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Calcareous Deposits of the Georgia Strait Area

By

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INTRODUCTION.

This bulletin includes reports of surveys of most of the known commercial or potentially commercial calcareous deposits readily accessible to the industrial and agricultural areas of south-western British Columbia and north-western Washington. Limestone deposits on the west coast of Vancouver Island and on the inland passage north of the difficultly navigable waters of Seymour Narrows, Okisollo Channel, and Yuculta Rapids have not, however, been examined. Deposits more than 4 or 5 miles from tide-water have likewise been omitted from the study, except in the eastern part of the Fraser Valley and in the western part of the Cascade Range of Washington where adequate road or rail transportation is available. Unconsolidated calcareous deposits, marl, travertine, and shell, which are of some economic importance within this area, have been included in the study.

Three introductory chapters dealing with the geology, extraction and utilization, and examination of these western limestone deposits have been included in this bulletin to aid in the appreciation of the reports on individual properties.

Three months of the summer of 1944 were devoted to field-work on Texada Island, and two months of the summer of 1945 to field-work on Vancouver Island and the Lower Mainland. Brief visits were made to operating and recently operating deposits in the State of Washington in December, 1945. J. G. Fyles and W. E. Redpath in 1944 and W. C. Thomson and R. R. Steiner in 1945 assisted in the field-work. The manuscript for this bulletin was written in the first half of 1946.

The writer wishes to acknowledge the assistance extended to him by the operators of the various deposits, by W. S. Planta, of Texada Island; Dr. H. C. Gunning, of the University of British Columbia; and by many others encountered during the course of the work.

DEFINITIONS, CHEMICAL SYMBOLS AND ABBREVIATIONS.

The classification of limestone used in this bulletin follows closely that used by Goudge in "Limestones of Canada,"* differing from Goudge principally in using "High-calcium Limestone" as a separate class rather than part of the "Calcium Limestone" class.

Limestone denotes a rock of sedimentary origin consisting mainly of calcium carbonate (calcite) or the double carbonate of calcium and magnesium (dolomite). A rock containing less than 50 per cent.† combined calcite and dolomite is, therefore, not considered to be a limestone.

Limestone may be subdivided on the basis of chemical composition into four classes:—

(1.) *High-calcium Limestone.*—Denoting a limestone containing at least 95 per cent.† calcium carbonate ($CaCO_3$) and not more than 2 per cent. magnesium carbonate ($MgCO_3$); these are equivalent to 53.3 per cent. lime (CaO) and 0.96 per cent. magnesia (MgO).

(2.) *Calcium Limestone.*—Denoting a limestone whose calcium content greatly predominates, but which cannot be classed as high-calcium limestone.

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* Goudge, M. F.: Limestones of Canada—Mines Branch, Dept. of Mines, Ottawa.

† All percentages are by weight.

Calcium limestone may contain up to 4.79 per cent. magnesia, equivalent to 10 per cent. magnesium carbonate.

(3.) *Magnesian Limestone.*—Denoting a limestone containing more than 4.79 per cent. and less than 19.15 per cent. magnesia.

(4.) *Dolomitic Limestone.*—Denoting a limestone containing more than 19.15 per cent. and less than 21.86 per cent. magnesia, the theoretical magnesia content of the mineral dolomite.

The term *dolomite* is restricted to the pure mineral ($CaMg(CO_3)_2$). The term *marble* is used in this report in its geological sense as crystalline limestone, not in the popular sense as an ornamental limestone.

In the chemical analyses quoted in this bulletin the components of limestone are given in terms of oxides and " ignition loss," the latter consists chiefly of carbon dioxide (CO_2). The essential oxides in limestone, lime (CaO), and magnesia (MgO) are reported in some publications as calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$). These oxides may be recalculated as the carbonates or vice versa using the following data:—

1 per cent. CaO is equivalent to 1.78 per cent. $CaCO_3$.
1 per cent. MgO is equivalent to 2.09 per cent. $MgCO_3$.
1 per cent. $CaCO_3$ is equivalent to 0.560 per cent. CaO.
1 per cent. $MgCO_3$ is equivalent to 0.478 per cent. MgO.

In order to save space, chemical formulæ and other abbreviations have been used in the tables of chemical analyses throughout this bulletin. The abbreviations used are explained below:—

Symbolic Formula.	Full Chemical Name.
Fe_2O_3	Iron oxide; contains 69.94 per cent. iron by weight.
MnO	Manganese oxide; contains 77.44 per cent. manganese by weight.
P_2O_5	Phosphorous pentoxide; contains 43.65 per cent. phosphorous by weight.
TiO_2	Titanium dioxide; contains 59.95 per cent. titanium by weight.
Al_2O_3	Aluminium oxide (alumina); contains 52.91 per cent. aluminium by weight.
CaO	Calcium oxide (lime); contains 71.47 per cent. calcium by weight.
MgO	Magnesium oxide (magnesia); contains 60.32 per cent. magnesium by weight.
S	Sulphur.
Insol.	Acid insoluble matter; contains those minerals, chiefly silicates, which do not dissolve when heated with hydrochloric acid as described on page 31.
R_2O_3	Aluminium oxide, with those oxides of titanium, zirconium, beryllium, chromium, quinquavalent phosphorous, quinquavalent arsenic, and quinquavalent vanadium present in the limestone. Usually for limestones R_2O_3 is essentially aluminium oxide, the remaining substances listed being present in very low percentages if at all.
Ig. Loss	The percentage loss in weight when the limestone is ignited in a furnace. Such ignition decomposes the carbonates of calcium and magnesium, forming calcium and magnesium oxides and gaseous carbon dioxide. This carbon dioxide escapes and, together with the minor amounts of water and organic matter present, accounts for practically all the loss in weight on ignition.
H_2O 105°	Water which is released from the sample when it is heated at 105° Centigrade.

CHAPTER I.—GEOLOGY.

ORIGIN OF CALCAREOUS DEPOSITS.

Carbonates of calcium and magnesium may be precipitated from aqueous solutions, usually sea water, by several different agencies. The calcareous deposits thus formed may be subdivided into several more or less independent types based on their modes of origin:—

(1.) Those consisting of the accumulated shells, or fragments of shells, precipitated by the larger organisms.

(2.) Those precipitated by micro-organisms in which shells or shell fragments are not evident, at least to the unaided eye.

(3.) Those precipitated by chemical means, such as a change in the temperature or in the CO_2 content of the solution.

(4.) Those composed of any two or all of the above agencies.

Except where limestones have been extensively recrystallized, those formed by the accumulation of larger shells and shell fragments are easily recognizable. Where the limestone is fine-grained and devoid of visible shells or shell fragments, however, the origin may be doubtful. Such a limestone may have been precipitated originally as a fine-grained ooze, either by micro-organisms or by chemical action, or by a combination of the two. Where shells and shell fragments are found in a matrix of fine-grained limestone, larger organisms and also micro-organisms or chemical action, or both, were responsible for the original deposition. Such a case is found at one horizon in the limestone of Texada Island where, however, shell fragments are exceedingly widely scattered. It is clear that this horizon and the adjacent unfossiliferous limestone originated almost entirely through microbiological or chemical action. The scarcity of shells in most of the limestone deposits, except in some of the Palæozoic crinoidal limestones of the area, suggests that larger organisms played but a minor part in the precipitation of the original material, but in several deposits the recrystallization of limestone has been sufficient to obliterate fossil remains and their origin must remain in doubt.

Submarine vulcanism, according to Kania,* may play an important part in the precipitation of limestone by heating the overlying sea-water, eliminating much of its content of carbon dioxide, and converting the dissolved calcium bicarbonate to insoluble calcium carbonate. The precipitated ooze, he believes, may be carried by submarine currents into hollows in the sea-floor to give rise to thick but lenticular deposits of limestone.

Nearly all the limestones of the area studied were evidently deposited as limy ooze, marine shells, etc., on ancient sea-floors. Under these circumstances uniform conditions apparently prevailed over many acres or even many square miles of sea-floor for appreciable periods of time. During such a period several inches to several feet of calcareous material might be deposited and would retain fairly uniform physical and chemical characteristics throughout. At the same time greater or less amounts of mud and sand or volcanic ash might be deposited with the calcareous material, and thus contribute to the impurities present in the resulting limestone. For any one of several reasons conditions might change and sedimentation cease, or sediment of a different character be laid down. In this way a deposit consisting of roughly horizontal layers of different compositions would be formed. A gradual change in conditions would lead to a progressive change in the physical characteristics and composition of the sediment being laid down. Similarly an abrupt change in conditions would produce a distinct discontinuity in the character of the sediment. At the present time such discontinuities between successive strata are in many cases marked by conspicuous joints, which may be termed "bedding-fractures."

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* Kania, J. E. A. (1929): Precipitation of limestone by submarine vents, fumaroles, and lava flows—*Am. Jour. Sci.*, 5th Ser., Vol. 18, pp. 347–359.

Not all the limestone-deposits of the area were, however, laid down in marine waters or under the circumstances described above. Some limy oozes have been and are being deposited in fresh-water lakes as "marl." Organisms, notably the aquatic plant *Chara*, have been credited with assistance in the precipitation of this fresh-water marl. As in the case of marine deposits, marl may display more or less distinct stratification. The conditions suitable for precipitation of marl must be distinctly limited, for of all the lakes in the area studied only Cheam Lake in the eastern part of the Fraser Valley is known to contain marl. Marl deposits are commonly found in the lakes of the interior of British Columbia and Washington, where a drier climate prevails, and in many, but not all, cases in the vicinity of large outcroppings of limestone.

Calcareous waters issuing onto the land surface as springs, entering caves, or percolating through surface soils may deposit calcareous material known as "travertine." The compact but cellular form of travertine is commonly referred to as "tufa." Physico-chemical action, such as concentration of dissolved carbonates by evaporation loss of carbon dioxide, and change in temperature, is probably chiefly responsible for the deposition of travertine. Large deposits of travertine are rare in the Georgia Strait area, only one commercial deposit, at McMillin, near Tacoma, being known.

Low-grade calcareous deposits may be reworked by various agencies and in some cases become concentrated. Clam-shells and shell fragments scattered across the sea-bottom may be transported by waves and currents, cast up on the shores, and washed to leave layers of high-grade shell-sand. The native Indians, who for centuries collected clams and mussels for food, have left in places near the coast concentrations of their shells in kitchen-middens. These two types of shell deposits have locally been sufficiently large and high grade to have been worked commercially. The mechanical erosion of limestone and subsequent deposition of undissolved detritus can take place, and a deposit at Departure Bay may possibly have originated in this way.

The original calcareous deposits as first laid down are believed to have been in general composed dominantly of calcium carbonate. Some marine shells, however, do contain considerable quantities of magnesia, and this constituent may be retained in the resulting deposit. Selective solution of calcium carbonate from these shells may lead to a concentration of magnesia in the residue. Such a process may be responsible for some deposits of magnesian limestone. It is considered, however, that most of the magnesia contained in limestone has been introduced by reaction between sea-water and part or all of the calcareous sediment during or shortly after its deposition and prior to its deep burial. Such a reaction gives rise to beds or fine laminæ of magnesian or dolomitic limestone interstratified with calcium-rich limestone. Such beds or laminæ are composed either of grains of dolomite disseminated through a calcite matrix or of nearly pure dolomite.

Silica (SiO_2) may be introduced, like dolomite, into the sediment during or shortly after its deposition as jelly-like layers or masses. Such a gel, subsequently converted into flint or chert, commonly takes the form either of nodules, of various sizes and shapes, arranged in groups parallel to the stratification, or of more or less continuous beds. Silica in the form of sand grains may also be incorporated with the calcareous sediment, but this form is rare.

Other impurities that may be introduced along with calcareous material in the original sediment include mud (rich in alumina and insoluble matter), volcanic ash (rich in insoluble matter), and carbonaceous matter from organisms.

The limestone-beds themselves may be overlain and underlain by bedded material of a totally different composition, notably shales, argillites, and schists, cherts, and volcanic rocks.

MODIFICATIONS OF CALCAREOUS DEPOSITS.

Most of the calcareous deposits, as originally formed, consisted of horizontal or nearly horizontal strata, each of which possessed more or less uniform physical and chemical characteristics. In at least the older deposits the original structure has, however, rarely been left undisturbed. The formerly flat-lying strata have been tilted, warped, and in some cases complexly folded. Strata have been fractured and faulted into more or less isolated blocks of all sizes. Careful study is in many cases necessary to recognize the original stratification and to decipher the complex structures into which it has been deformed. Nor is the structure alone modified; the texture of the deposit, too, may be altered by the action of heat and pressure working over long periods of time, converting limy ooze to the solid rock known as limestone and recrystallizing limestone into marble.

FOLDING.

One limestone-deposit in the area exhibiting a simple folded structure is that at Limekiln Bay, in the northern part of Texada Island (Fig. 1, page 12). Here on shore cliffs and in an old quarry is exposed the western part of a broad saucer-shaped structure. The strata dip, in general, towards the centre of this structure at angles of not more than 20 degrees. Some beds can be traced for the full length of the quarry-face, some 400 feet; others exposed at opposite ends of the quarry lie below the level of the quarry-floor in its central part.

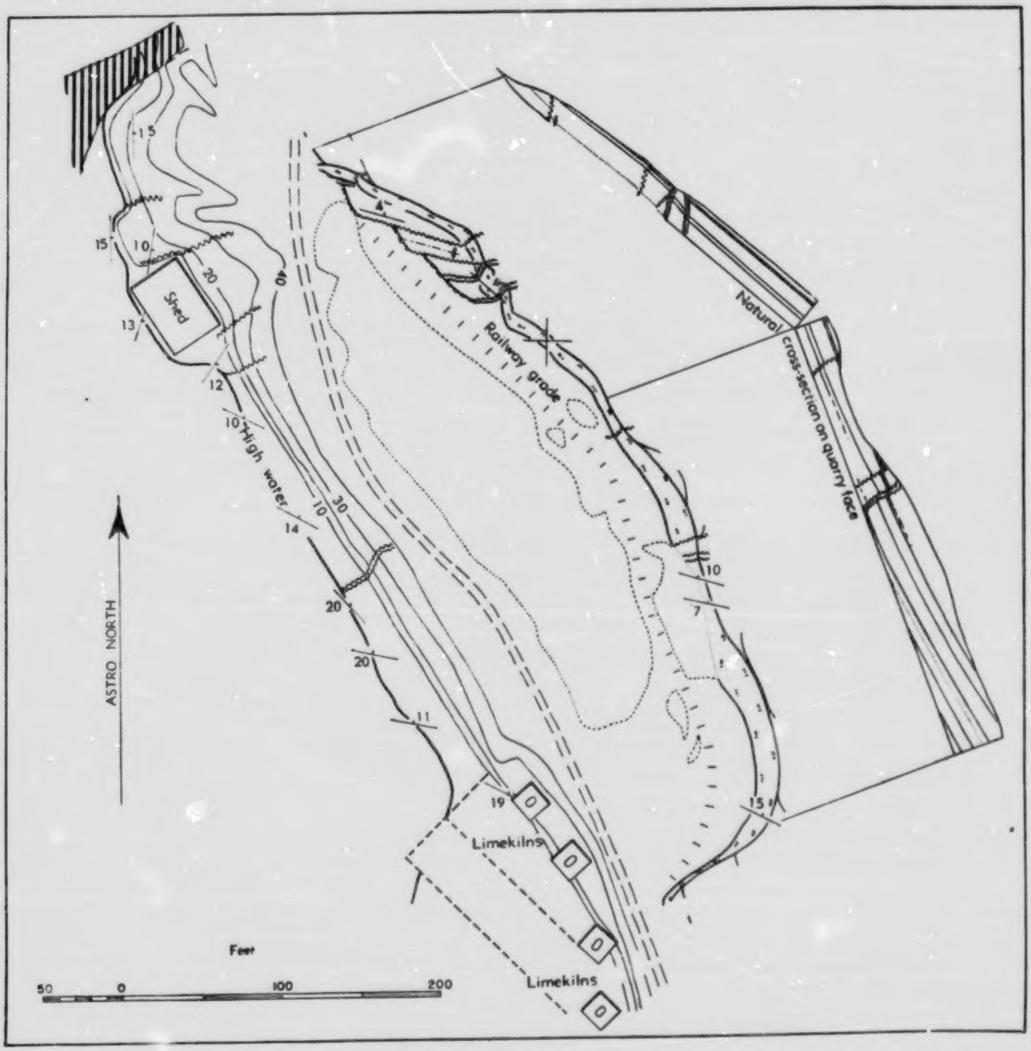
The limestone at Open Bay, Quadra Island, on the other hand, exhibits intense and complicated folding (Fig. 16). Here beds or laminæ of argillaceous limestone in purer limestone show crenulations on the flanks of small drag-folds situated, in turn, on the flanks of still larger folds. In any one part of the deposit the axial planes of the crenulations, drag-folds, and larger folds have a rough parallelism. In some parts of the deposit, however, the folds may be upright, elsewhere overturned either to the east or west, and in one place the folds are recumbent. Lacking some readily recognizable stratigraphic horizon it would be exceedingly difficult to determine whether the regional dip of the deposit is to the east or west. Fortunately, however, several lava-flows are interbedded with the limestone, and although these, too, exhibit larger-scale folding it is clear that they and the limestone with them dip at moderate angles to the east.

Between these two extremes in intensity of folding all degrees may be found in the limestone-deposits of the Georgia Strait area. No extensive flat-lying deposits of limestone, such as occur in the Palæozoic rocks of southern Ontario or of the Middle-west States, exist in this area.

FAULTING.

Some of the clearest examples of faulting to be found in the area occur in the quarry at Limekiln Bay (*see* Fig. 1) and on the adjacent shore cliffs. Here the saucer-shaped folded structure is complicated by two sets of easterly-trending, southward-dipping normal faults. The beds on the south sides of these faults are in each case dropped with respect to the corresponding beds on the north sides by amounts varying from a few inches to more than 10 feet. Here the reason for the present discontinuity in the strata or in rock of a given chemical composition is clearly evident. In this exposure it is also apparent that the dip of a single fault may change from bed to bed. Moreover, the displacement at different parts of the same fault shows distinct variations. One small fault at the north end of the quarry dies out up the dip, the displacement varying from about 2 inches at the quarry-floor to zero a few feet higher. The sum of the displacements in the southern set of faults is at the quarry-face almost 8¾ feet, and at the shore cliffs, 200 feet to the west, 11½ feet.

Similar features are found in faults elsewhere in the area, although they are nowhere as well revealed as at Limekiln Bay. In some of the limestone-deposits of the area faults are of considerable magnitude, one on Texada Island is estimated to have a displacement exceeding 1,000 feet. Where the fault movement has a horizontal component or where a fault cuts tilted beds, it can be detected by the displacement in plan view of beds, contacts, or other formerly continuous features. In many cases faults can be recognized by the termination of a given stratum at a zone of crushing, but the direction and amount of the displacement can not be determined. In most cases in deposits within the area the abrupt termination of a limestone-bed along its length can be attributed to faulting.



-15
15
10
13
Shed
20
40
12
10
High water
10
30
14
20
20
11
19
Limekilns
Limekilns
Railway grade
Natural cross-section on quarry face
10
7
15
ASTRO NORTH
Feet
50
0
100
200

Fig. 1. Limekiln Bay quarry. Bar pattern—dyke rock.

TEXTURAL CHANGES.

The calcareous sediment most nearly in its original condition is the fresh-water marl of Cheam Lake. The stratified jelly-like ooze at the bottom of this lake is so soft that it can be stirred into a pulp and pumped through a 3¾-inch pipe. The relatively undisturbed limestone of Limekiln Bay and of the south-western part of Blubber Bay has become converted during millions of years from what was probably a similar ooze when first laid down on the sea-floor into solid limestone, which, however, retains the former fine-grained texture and a dark colour contributed by finely disseminated carbon presumably inherited from former organisms.

Limestone has been converted into a coarse-grained marble in the vicinity of some intrusive igneous rocks, which for a time must have contributed considerable heat to the adjoining calcareous rocks. Such marble at the west end of No. 1 quarry, Beale Quarries, Limited, Vananda, contains calcite crystals from 1 to 1½ inches in diameter, and calcite crystals 4 inches across are reported by Swanson* (1924, p. 115) from the limestone at the Texada Island iron mines. Rarely, however, does the grain size of marble reach such dimensions.

Limestone has developed a characteristic gneissic banding of dark carbon-rich and light carbon-poor bands, each usually a fraction of an inch thick in areas of tight folding, such as that extending along the east coast of Texada Island from Grilse Point to Eagle Bay. This gneissic structure is apparently related to shearing along bedding-planes during folding. It is best defined along the flanks of folds and is ill-defined or missing at their axes. Gneissic banding is not necessarily parallel to the bedding; indeed there is probably a tendency for it to parallel the axial plane of folds irrespective of bedding. Shearing movements unrelated to folding may be responsible for belts of similar gneissic limestone in gently folded rocks. Such an occurrence was found at one place west of the Vananda Road in the Pacific Lime Company's property at Blubber Bay, Texada Island. At one point on the north shore of Sturt Bay, Texada Island, two sets of intersecting gneissic bands were observed.

INTRODUCTION OF EXTRANEOUS MATERIAL INTO CALCAREOUS DEPOSITS AFTER DEPOSITION.

INTRUSIVE ROCKS.

In some of the limestone-deposits of the area extraneous material has been introduced in the form of dykes and sills, injected originally as molten rock along fractures in the limestone, either cutting across or parallel with the stratification. These dykes and sills vary markedly in colour, texture, and in chemical composition, although all are high in insoluble matter. In some parts of the area, notably in the northern part of Texada Island, they are sufficiently abundant to add materially to the problems of extraction and treatment of limestone. Further details on these dykes and sills are given in the descriptions of the various deposits.

Some of the limestone-deposits have been invaded by larger intrusive masses. In the northern part of Texada Island the limestones have been intruded by several gabbro to quartz diorite stocks, roughly elliptical in shape, from a few hundred feet to more than half a mile across. Rarely has any limestone been left within the area occupied by these stocks.

Very large areas in the Coast Mountains and considerable areas on Vancouver Island and in the Cascade Range have been invaded by granitic batholiths. In parts of the batholiths roof pendants or large inclusions of older rocks, a part or all of which may consist of limestone, do exist, hence these batholiths cannot be overlooked in prospecting for limestone-deposits. Near Bold Point on Quadra Island, and a few miles north-west of Powell River, several such roof pendants or inclusions of limestone are known and are large enough to be of possible commercial interest.

VEINS AND REPLACEMENTS.

Veins and replacements of a wide range of mineralogical character in the limestone-deposits of the area have been formed, presumably by the precipitation of material from aqueous solutions percolating along fractures and through permeable zones. Some of these veins and replacements appear to have been produced by the redistribution of constituents already within the limestone of the vicinity, others were clearly derived from more distant sources.

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* Swanson, C. O. (1924): The genesis of the Texada Island magnetite deposits—*Geol. Surv., Canada*, Sum. Rept. for 1924, Pt. A, pp. 106–144.

In the first of these two classes may be included veinlets of dolomite, calcite, and serpentine, and grains and irregular masses of olivine, serpentine, etc. Fine veinlets of dolomite cutting across calcium-rich limestone are common features in many of the limestone-deposits of the area. Such veinlets are, however, most abundant within a foot or two of beds of dolomitic or magnesian limestone, and it is evident that these beds are the source of the magnesia in the veinlets. No large irregular masses of dolomite which might be formed by the introduction of large amounts of foreign magnesia are known. Veinlets of calcite similar to those of dolomite are common in beds of magnesian and dolomitic limestone, and though in some cases they extend many feet from the nearest calcium-rich bed they, too, are presumably of local origin.

Grains of olivine and small veins and segregations of serpentine are apparently formed as a result of metamorphism by the recombination of magnesia and silica in magnesium-rich limestones, with or without the introduction of additional silica.

In the second of the two classes may be included vein-like to more or less irregular replacements, known as "skarn," consisting of lime silicates, chiefly garnet, diopside, wollastonite, etc., with varying amounts of pyrite, magnetite, chalcopyrite, bornite, etc. These skarn-bodies occur in several of the limestone-deposits of the area but are most common on the northern part of Texada Island where several have been mined for their copper-gold or their iron content, and similar bodies too small and too low grade to be mined for their metal content are large enough to interfere with limestone quarrying. The skarn-bodies are younger than most of the intrusives commonly occurring along their contact, partly within the intrusives and partly within the intruded limestone. A few bodies lie many feet from the nearest intrusive, commonly either along a prominent fracture or along a fold axis. It is apparent that the former content of silica, iron, sulphur, etc., of the adjacent limestone was totally insufficient to provide for these skarn-bodies by a process of segregation and therefore that these constituents must have been introduced from more distant sources. It is equally clear, however, that much of the material in the skarn was formerly present in the host rock. The calcium-magnesium ratio in the skarn, for instance, approximates that of the limestone within which it is found, hence it may be concluded that neither of these constituents was added. In some cases it is possible to trace intrusive contacts and stratification in the limestone across skarn-bodies.

Some pyrite, etc., is found extending for many feet along thin and minutely contorted argillaceous beds in certain localities, as for example in the Little Billy quarry, Texada Island. Whether or not the pyrite has been introduced here as in the typical skarn-deposits or is part of the original sediment is not known.

CLASTIC DYKES.

Clastic dykes occur in many of the limestone-deposits but are of minor importance except in the uppermost few feet of bed-rock. These clastic dykes usually consist of fractures and solution fissures filled with cream-coloured sand and gravel washed from the overlying glacial drift. A few of these dykes in the northern part of Texada Island are filled with a characteristic green sand and gravel, clearly derived from the greenstone intrusives cutting the limestone in their vicinity. Since the latter dykes contain no material of glacial origin it is possible that they are of pre-Glacial age.

WEATHERING OF CALCAREOUS DEPOSITS.

In unglaciated areas limestone is commonly covered by a layer of residual soil made up of insoluble matter from decayed limestone. All the limestone-deposits of the

Georgia Strait area have, however, been glaciated, and any such residual soil which may have been developed prior to the ice age has since been stripped away. These deposits are, therefore, either bare or covered by glacial and fluvioglacial debris transported from adjacent areas and usually containing only small amounts of calcium carbonate. Probably the surface layer of limestone affected by post-Glacial weathering and solution is no more than a few inches thick, except in the vicinity of running water, along wave-swept shores, and in fractured zones.

MINERALOGICAL COMPOSITION OF LIMESTONES AND THEIR COMMON IMPURITIES.

Calcite and Dolomite.—As indicated earlier, calcite and dolomite are the two essential constituents of limestone. In all but the highest-grade calcium-rich limestones within the area studied the mineral dolomite has been recognized and is present in amounts approximately sufficient to account for the magnesia content indicated by chemical analysis. Calcite and dolomite are similar in many respects. Calcite has a hardness of 3, dolomite a hardness of 3.5. Calcite has a specific gravity of 2.71 to 2.72, dolomite a specific gravity of 2.8 to 2.9. Both minerals possess rhombohedral cleavage. Their optical properties are likewise similar. In some respects, however, the minerals are markedly different. Calcite dissolves readily in cold dilute acid with vigorous effervescence; dolomite is relatively insoluble. The rate of reaction of dolomite with other reagents is likewise much slower than that of calcite. Calcite recrystallizes much more readily than dolomite, hence with an equivalent degree of metamorphism high-calcium limestone gives rise to a much coarser-grained rock than does dolomitic limestone. Dolomite tends to assume its typical crystal form, the rhombohedron, at the expense of calcite which, therefore, in magnesium limestone, occupies the interstices between dolomite grains.

Silica-bearing Minerals.—Silica may occur in limestone in the form of grains of quartz deposited with the original sediment and of nodules and streaks of flint or chert introduced during, or but slightly after, deposition of the sediment. Within the limestones of the area no veins of hydrothermal quartz in contact with limestone are known. Any such hydrothermal silica presumably enters into combination with the limestone to produce lime silicates. Silica may also exist in limestone in combination with other substances, as for example in clay minerals and feldspar grains, etc., accumulated in the original sediment, formed subsequently by the reconstitution of these original impurities or introduced long after deposition. The distribution of silica-bearing minerals may, therefore, be concordant with the stratification or may be completely independent of stratification. Most of the silica-bearing minerals are insoluble in nitric, sulphuric, or hydrochloric acids, and these, together with the silica contents of the few partially soluble silicates and such non-silicate minerals as carbon, are reported in the analyses quoted in this bulletin as " insoluble matter."

Iron-bearing Minerals.—Iron may exist in limestone in the form of: carbonates —siderite, $FeCO_3$; and ankerite, $Ca(Mg, Fe)(CO_3)_2$: sulphides—pyrite, FeS_2, chalcopyrite, $CuFeS_2$; etc.: oxides—hematite, Fe_2O_3; limonite, $Fe_2O_3.nH_2O$; magnetite, Fe_3O_4: and silicates—olivine, $(Fe, Mg)_2 SiO_4$; chlorite; garnet; etc. Some of these minerals, like those containing silica, were original, some were formed by recombination, and some were subsequently introduced. Iron-bearing impurity in limestone may, therefore, be distributed more or less concordantly with the stratification of the limestone or may be totally independent of it. In the procedure adopted for analyses given in this report (*see* page 32), all the iron present in the sample, whether in soluble or in insoluble minerals, is reported as Fe_2O_3. Some of the iron minerals are insoluble in acid, hence are included with the " insoluble matter."

Alumina-bearing Minerals.—Argillaceous limestones are rich in alumina as are also some tuffaceous limestone. The alumina-bearing minerals present in limestone include clay minerals, micas, feldspars, garnets, etc., and being essentially a part of the original deposit tend to be distributed more or less uniformly in any bed. In the chemical analyses quoted, alumina, along with titania and manganese oxide, is included in "R_2O_3."

Sulphur.—Either as an original or an introduced constituent of limestone, sulphur may occur in the form of metallic sulphides, notably pyrite, chalcopyrite, etc., as hydrogen sulphide occluded within the rock and, possibly, as sulphates.

Carbon.—The carbon, which was presumably derived from organic matter entombed during sedimentation, contributes to the limestone its dark colour. As little as 0.1 per cent. elemental carbon is sufficient to give limestone a black colour. In some foliated limestone found on Texada Island, carbon tends to segregate into bands.

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CHAPTER II.—QUARRYING AND PROCESSING.

GENERAL PROCEDURE.

Most of the limestone in the Georgia Strait area is obtained from shelf quarries opened in hillsides. In these quarries there are no problems of drainage, hoisting, etc. Where, for various reasons, as for example the presence of steeply dipping walls on all sides of a limestone-deposit, the horizontal extent of a quarry but not its depth is limited, the deposit may be worked by a pit quarry, as at Blubber Bay and Tod Inlet. Glory-holes, funnel-shaped pits from which broken limestone is drawn through chutes, loaded underground into cars, and trammed to the surface, have been worked at Blubber Bay, Bamberton, and Concrete. In this method the need for power-shovels is eliminated but the problems arising when large blocks plug the loading chutes offset this advantage. None of these glory-holes has been operated since about 1932. No attempt has been made in the Georgia Strait area at large-scale underground mining of limestone.

The limestone-deposits in this area are worked, as a rule, in one or more benches each with a vertical or steeply sloping working-face. These faces may be from a few feet to 150 feet in height, and from a few tens of feet to about 1,000 feet long. Holes are drilled into the bench by drills generally set up on the quarry-floor at the base of the working-face and on the level above this face. The drill-holes are generally arranged in a definite pattern, comprising horizontal " lifters " drilled at the level of the quarry-floor, " breast-holes " started on the face a few feet above the quarry-floor and commonly inclined at a low angle upwards, and " down holes " drilled vertically downwards from the top of the bench from a few feet to as much as 35 feet behind the quarry-face. In some of the quarries no standard drilling round is adopted but drills are set up on the floor, face, or top of the bench, wherever convenient, and a round improvised to meet the local circumstances. The former method, being systematic, is simpler and more economical, but is less adaptable to irregularities in the ground surface, to variations in the character of the rock, etc. Hand-steel is used, but only in a few small " white-rock " quarries; percussion drills powered by compressed air are used in most of the smaller quarries; " wagon drills," large compressed-air drills on wheeled mountings, are used in most of the larger quarries; and well or churn drills are used only in the largest quarries and only for " down " holes. When the drilling of a round of holes is completed they are loaded with dynamite, all the charges detonated simultaneously, or nearly so, and a few tons to several hundred thousand tons of limestone broken in a single " primary blast."

After the primary blasting any loose rock is barred or blasted down from the face to prevent subsequent rock-falls which could be hazardous to workmen on the quarry-floor. Larger blocks which have come to rest on the floor may be broken by sledging or by secondary blasting, the latter either by mudcapping (bulldozing) or plug-holing (block-holing), to facilitate handling.

The broken limestone is then loaded, generally by power-shovels, into trucks or railroad-cars. In a few of the quarries the rock is loaded by hand into steel pans or detachable truck-buckets and hoisted onto trucks, or loaded directly into small mine-cars.

Limestone is generally crushed and sized before shipment. In some cases large blocks, weighing approximately 100 lb., are sorted out by hand and shipped directly as " man rock." Commonly, however, the broken rock is passed across a grizzly to eliminate fines. The oversize may then be broken by means of gyratory and jaw crushers. Ground limestone, generally handled in a dry state, except in cement manufacture, is commonly pulverized in a hammer-mill, or, less often, in a ring-roll or in a ball-mill. In many cases the grain-size of the ground limestone is determined by the spacing of the mesh-bars in a hammer-mill, or in other cases it may be sized in a revolving or vibrating screen. The limestone may be distributed in bulk, as is generally the case with the coarser products, or in paper sacks as in the case with the finer products.

INFLUENCE OF IMPURE BEDS AND IGNEOUS BODIES ON QUARRYING AND PROCESSING OF LIMESTONE.

Where, because of the presence of impure beds or of igneous bodies, only a part of a limestone-deposit is of a desired grade, some modification of the procedure of extraction and processing is necessary. In one method a segregation is made before quarrying and only the purer beds free from igneous bodies are extracted; in a second method pure limestone and impurities are quarried separately, the segregation being made during the course of quarrying; and in a third method the entire deposit is quarried and the impurities subsequently segregated.

If only the beds of the desired grade are quarried, it may be necessary to open in the deposit one or more partly or completely isolated quarries whose size and economy of operation depend firstly on the thickness of beds which can be quarried as a unit to obtain the desired grade, secondly on the inclination of these beds, and thirdly on their freedom from igneous bodies. The width of strata on a horizontal bed-rock surface—that is, the width in plan—depends upon the thickness of the strata and their inclination. In selective quarrying, this plan-width of the purer beds of limestone, or of that portion of the purer beds which can be exposed economically by removing overburden, limits the width of the quarry at the bed-rock surface. Also, since a certain slope to the quarry-walls must be maintained for the sake of safety, the width of the quarry tends to diminish at depth even if a foot-wall of impure rock is not encountered. The amount of limestone that can profitably be extracted by this method of quarrying may, therefore, be much less than the amount present in the deposit. Therefore, where the purer beds are relatively thin or igneous bodies common, the size of the quarries might be so small that their cost of operation would be prohibitive.

In the second method, in which high-grade limestone and impurities are quarried separately, several alternative procedures are possible. Limestone, for example, may be quarried up to its contact with a steeply dipping dyke, the face then cleared, the dyke blasted down and removed to the waste dump, and the quarrying of limestone beyond the dyke resumed. Again, where beds are flat-lying, it may be possible to quarry impure beds in separate benches and in this way segregate high- and low-grade rock. By the first method, selective quarrying of a high-grade bed overlain by an impure bed or an igneous body is possible for only a short distance down the dip before the danger of the collapse of the overhanging wall becomes imminent. In this case the second method of quarrying is adopted wherever the cost of removing the overhanging material is justified by the value of the additional high-grade rock made accessible for quarrying. As a result of these and similar variations of this second method, larger quarries can be obtained than by the first method, but at the expense of handling a greater amount of waste rock.

In the third method both high-grade limestone and impurities are quarried together and subsequently segregated. During the course of quarrying, a small amount of impure material, whether this be low-grade limestone or igneous rock, etc., tends to become mixed with a considerably greater amount of the higher-grade limestone. A steeply dipping dyke trending at right angles to the quarry-face, for example, is distributed through and thus contaminates a volume of broken limestone out of all proportion to the size of the dyke. It may, nevertheless, be possible to segregate this contaminating rock during loading and to discard it or to dispose of it as low-grade limestone. Where loading of broken limestone is carried on by hand it is readily possible to sort out at least the larger blocks of dyke-rock. Impure limestone can also be segregated during quarrying and loading, although less readily than the easily distinguishable igneous rocks. In a few places, notably in the Lehigh Valley of Pennsylvania, the grade of limestone after it has been ground is improved by a process of selective flotation, but no such method has been adopted in the Georgia Strait area.

INFLUENCE OF OVERBURDEN AND SURFACE LIMESTONE ON QUARRYING AND PROCESSING OF LIMESTONE.

Overburden—gravel, sand, silt, clay, and glacial till—if mixed with broken limestone during quarrying can contaminate it just as readily as do impure limestones and igneous rocks. It is customary, however, to remove overburden by stripping prior to quarrying, much as, for example, a cover of impure limestone might be removed in an upper bench to expose underlying high-grade limestone. Such impure rock, however, might have a sale value as low-grade limestone, but overburden has generally no such value. The expense of removing and disposing of the overburden covering a given area is justified only if marketable limestone of sufficient value is exposed by the stripping.

Open solution cracks, common in the upper few feet of the limestone-deposits, not only add difficulties to drilling and blasting, but also are apt to contain considerable amounts of unconsolidated material which contaminates the quarried product. This surface limestone must, nevertheless, be removed to make accessible the underlying more readily quarried and less contaminated rock.

The unconsolidated material, occurring as a thin mantle of drift, as a residue from stripping operations, or as the filling of solution cracks near the surface, can be segregated from the broken limestone either by grizzlies, screens, or hand-sorting.

INFLUENCE OF TOPOGRAPHY ON QUARRYING.

Topography has a marked influence on both the type of quarry developed for the extraction of limestone and on the initial cost of development.

Where the limestone is exposed on a horizontal land surface it can be extracted only by a pit quarry; where limestone is exposed on a sloping surface it can be extracted by a shelf quarry in which problems of hoisting and drainage can be eliminated; where, however, the limestone is exposed on a steep or precipitous mountain-side this advantage is offset not only by the hazardous and inefficient height of quarry-face that is obtained as the face is advanced only a short distance, but also by the danger of rock-falls from the slopes above the quarry.

As considerable expense may be involved in opening a quarry, a limestone-deposit whose original surface approximates the form of the developed quarry-face is desired. In such a case a minimum volume of excavation or of filling is necessary to establish a flat floor on which mechanical equipment can be operated, and after a minimum of drilling and blasting, a face on which systematic quarrying can be conducted is developed. If, moreover, the surface in advance of the quarry-face is flat, a constant height of face can be maintained and a uniform and systematic quarrying procedure carried on. A bluff or cliff, of the height of the proposed quarry-face, rising from a flat base to a flat top, is therefore preferred, because it requires a minimum cost of development before a normal quarrying procedure can be established.

TRANSPORTATION.

Limestone is hauled from quarry to processing plant or shipping-point by means of trucks, narrow- or full-gauge railways, or aerial tramways. In general such hauls are short and relatively inexpensive. From processing plant or shipping plant to the ultimate market, limestone and limestone products are transported by truck at relatively high costs per ton mile, by rail at considerably lower costs per ton mile, or by barge at somewhat less cost again. As many of the hauls by rail and barge, however, exceed 100 miles, costs of transportation may approach the costs of quarrying and processing, and add considerably to the final price of the limestone. This relatively high cost of transportation permits the economical operation of smaller higher-cost quarries serving local markets, in competition with larger lower-cost but more remote quarries. Cement plants are generally established close to sources of limestone, and the cost of transportation to the ultimate market is borne by the higher-priced finished products. Sources of other raw materials, labour, and power, however, commonly determine the site of other lime- and limestone-consuming industries.

MARKETING.

Sales of limestone and limestone products are generally arranged either by an agent or by direct negotiation between producer and consumer. Prices and specifications are established by individual contract. In view of the wide variations in specifications and in the amounts of limestone, etc., purchased by various consumers the prices at shipping points vary markedly, and with the great variations in the distance and means of transportation, prices at the point of consumption have still wider ranges.

Canada and the United States impose duties on imports of limestone in certain forms and on imports of some products derived from limestone.

USES AND SPECIFICATIONS FOR LIMESTONE.

BUILDING INDUSTRY.

PORTLAND CEMENT.

Large quantities of limestone are used annually in the production of Portland cement. In the manufacture of this product* a wet-pulp or "slurry," consisting of about 75 per cent. calcium carbonate, 10 to 17½ per cent. silica, 2½ to 10 per cent. combined ferric oxide and alumina, and not over 5 per cent. combined magnesia and alkalis, is burned in a rotary kiln and the resulting clinker ground in a dry condition. Specifications of cements used for different purposes vary markedly, hence the kiln feed may differ somewhat from that given above. The mix is made up from limestone, siliceous material (quartz, sand, siliceous limestone or acid igneous rocks), and aluminous material (clay, shale or argillaceous limestone), in proportions which give the desired composition of kiln feed. Calcium-rich limestone, or somewhat impure argillaceous or siliceous limestone may, therefore, all be used in the manufacture of cement, but magnesian and dolomitic limestone are not suitable.

Five cement plants are operated in the area studied, one at Bamberton on Vancouver Island and four in the Puget Sound area of north-western Washington. All have their own limestone quarries.

The British Columbia Cement Company, Limited, of Victoria, operates a cement plant† with a rated capacity of 900,000 barrels (350 lb. per barrel) per year, at Bamberton, B.C., on Saanich Inlet. Calcium limestone for the cement is obtained from a quarry adjacent to the cement plant augmented by high-calcium limestone shipped by barge from a company quarry at Blubber Bay, Texada Island, 110 miles to the north.

Greenstone, intimately associated with the limestone of the Bamberton quarry, and clay, now being obtained from the Saanich Peninsula, supply the silica and alumina required in the cement.

This company was formed in 1918 by the amalgamation of the Associated Cement Company (Canada), Limited, with the plant mentioned above at Bamberton, and the Vancouver Portland Cement Company, with a plant at Tod Inlet.‡ The latter plant is now largely dismantled.

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* *See* Lea, F. M., and Desch, C. H.: The Chemistry of Cement and Concrete. *Ed. Arnold & Co., London.*

† Brewer, W. M.: *Minister of Mines, B.C.*, Ann. Rept. for 1926, pp. 334–337.

‡ Robertson, W. F.: *Minister of Mines, B.C.*, Ann. Rept. for 1904, pp. 256–260.

The Northwestern Portland Cement Company operates a cement plant with a rated capacity of 600,000 barrels (at 374 lb. per barrel) annually, at Grotto, Wash., on the Skykomish River, 48 miles east of Everett. Argillaceous limestone for this plant is obtained from a hillside quarry a mile and a half west of Grotto. It is reported that shale from Brennan, Wash., is used as an additional source of aluminous material.

The Olympic Portland Cement Company, Limited, at Bellingham, Wash., operates a cement plant with rated capacity of 900,000 barrels (374 lb. per barrel) annually. Limestone is obtained from the company's Kendall quarry, 34 miles east of Bellingham, silica from a quartz deposit in this same area, and clay from a pit near the plant.

The Superior Portland Cement, Incorporated, operates a large cement plant at Concrete, Wash.,* having a rated capacity of 2,000,000 barrels (at 374 lb. per barrel) annually. Argillaceous and siliceous limestone, obtained from a quarry 1 mile northeast of the plant, is sorted, stockpiled, graded, and mixed in the desired proportions. An excess of siliceous limestone obtained in quarrying is shipped to the Seattle plant of the same company.

The Superior Portland Cement, Incorporated, also operates the plant in Seattle formerly operated by the Pacific Coast Cement Company.* This plant has a rated annual capacity of 1,200,000 barrels (at 374 lb. per barrel). Calcium limestone has been obtained from Dall Island, Alaska, and shipped by the company's 6,500-ton freighter to the plant.

In general these plants are operated at full capacity only during periods of unusual demand, chiefly to fulfil contracts for the construction of major power projects, concrete airstrips, and highways. The remainder of the production is used for buildings, foundations, etc., and requirements may fluctuate markedly.

BUILDERS' LIME.

Lime is widely used in plaster, mortar, and whitewash, for which purposes it must satisfy certain specifications, notably as to grain size, rate of settling, soundness, plasticity, and colour. Such properties in lime are determined in part by the chemical composition, in part by the physical character of the limestone from which it is made, and in part by the conditions in processing. Limestone, for example, containing more than about 1 per cent. iron oxide (FeO) and about 0.03 per cent. manganese oxide (MnO) produces a lime having an undesirable buff to brown colour. Limestone containing more than 1 per cent. magnesia gives trouble in burning and the resulting lime plaster tends to blister or " pop." Physical characters of the limestone not only determine the ease or difficulty of burning, but may also affect other properties. The conditions of processing determine or affect final grain-size, rate of settling from a suspension, etc. It is not, in general, possible to determine merely from examination of a given limestone sample and from its chemical analysis whether it would be suitable for builders' lime. Burning tests, preferably in a model or full-scale kiln, and laboratory or field tests of the resulting lime are essential in indicating the value of a new limestone-deposit for this product.

The producers of builders' lime in the coast area are Pacific Lime Company, of Blubber Bay and Vancouver, B.C., and Roche Harbor Lime & Cement Company, Roche Harbor, Wash. Lime is also being shipped to the Puget Sound area from the Evans plant of the United States Gypsum Company in eastern Washington.

BUILDING-STONE.

A very limited amount of limestone and marble has been quarried in the Georgia Strait area for use as a building and ornamental stone. The reddish crinoidal limestone of Anderson Bay was for a time quarried by the Continental Marble Company and by A. Henderson, of Nanaimo, but no activity is known to have taken place in this area since 1916. The first quarry on Texada Island, on the north shore of Sturt Bay, was operated for a test shipment of ornamental stone by Capt. Sturt, prior to 1886. No further shipments are known to have been made from this quarry.

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* Hutton, S. E. (1929): Outstanding Portland Cement Plant—*Rock Products*, Vol. XXXII., No. 25, pp 33-51.

The excessive jointing of the limestone and marble deposits, together with the limited local demand for building and ornamental stone, is apparently responsible for the absence of this industry in the Georgia Strait area.

AGRICULTURE.

In inadequately drained, water-logged soils, the presence of carbonic acid and of organic acids formed by the accumulation and decomposition of vegetable matter gives rise to " sour " land. Where the rate of removal of soluble lime salts from the soil by cropping, and especially by the leaching effect of rain-water in excessively drained land, exceeds the rate of replacement of these salts by the weathering of insoluble calcium minerals, deficiency of available calcium ultimately results and soil acidity is apt to follow. Acid soils of both these origins are found within the Georgia Strait area, and the low, poorly drained, fine-grained Recent alluvial sediment brought down by such rivers as the Fraser is particularly apt to become acid. On extremely acid soils but few plants, notably peat-moss and the blueberry, find their optimum conditions; most plants grow but do not give their maximum yields, and some plants, notably the legumes, do not grow satisfactorily at all. The application of burned lime, hydrated lime, or ground limestone to the soil corrects acidity and may effect an increased production in many, but not all, crops.

The effect of liming acid soils is threefold—chemical, physical, and biological. The application of limestone or limestone products not only provides available calcium salts but the reduction of acidity may permit the conversion of insoluble potash and phosphorus compounds into soluble forms available for plant growth. Liming may also affect the physical characteristics of sticky clay soils by flocculating colloidal matter and thereby improving soil texture. In this way not only is drainage improved but the soils become easier and less expensive to till. Finally, the reduction of acidity may permit the growth of certain favourable organisms in the soil, notably several types of bacteria which create and make available nitrogen compounds for plants.

It will be understood that the necessity and amount of liming of soils varies not only with the character of the soils themselves but also with the nature of the crops to be grown on them. Liming of soils does not, in general, give rise to any enormous increase in crop yields as does the use of certain fertilizers. In some cases the improvement in soil texture may be the only appreciable benefit. In still other cases the improvements, if any, may be so limited as to fail to justify the cost of liming. The soil scientists within the Georgia Strait area have so far carried on insufficient experimentation to determine quantitatively how beneficial liming may be, and are, therefore, unable to voice a unanimous opinion on the merits of liming in certain of the common soil series. The need for lime or limestone in the lowland clay-soils of the area, notably the Ladner series of the Fraser Delta, however, seems unquestioned.

Hydrated lime, ground limestone, and marl are all suitable for liming soils. Burned lime (quicklime), which is difficult to handle, is not used for this purpose. Hydrated lime has the advantage of having a greater lime content (up to 76 per cent.) and of bringing about a quicker response in soils than ground limestone (lime content up to 56 per cent.). Ground limestone, on the other hand, produces no detrimental effects in case of an excessive application, as does burned and hydrated lime, and its influence may be prolonged over a period of years as the larger particles of limestone slowly dissolve. Marl is comparable in its effects to ground limestone.

The active ingredient, lime, in agricultural limestone products varies from about 76 per cent. in pure hydrate to less than 25 per cent. in some air-dried marl. Ground high-calcium limestone may contain 56 per cent. lime. In south-western British Columbia no valuation is placed on the magnesia content of the product, in spite of the fact that its effect in correcting soil acidity is comparable to that of lime. Most impurities in the limestone—moisture, silica, iron, etc., are inert; they neither contribute to its effects nor actively detract from them. They do, however, dilute the active ingredient and necessitate the use of a greater weight of product in obtaining a given effect on the soil. A few constituents, notably nitrogen and organic matter in marl and phosphorus in limestone, may be beneficial, but they are generally present in minor amounts. The price for lime, hydrate, ground limestone, and marl is, therefore, based on the lime content, plus cost of packaging, transportation, etc.

A Provincial Government subsidy, amounting to $1 per ton, has since April 1st, 1943, been granted to British Columbia farmers using agricultural lime or limestone, provided the product met the following specifications:—

(1.) Ground limestone must have a minimum calcium carbonate content of 85 per cent.

(2.) Ground limestone must be ground to a fineness that permits 100 per cent. to pass through a screen with 10 meshes to the linear inch, and at least 30 per cent. through a screen with 100 meshes to the linear inch.

(3.) Hydrated lime must have a minimum content of calcium hydrate of 85 per cent. and be of a fineness of texture comparable to that required for ground limestone.

Subsequently these specifications were altered to cover lower-grade limestone products and marl. Since January 1st, 1946, payments have been made on the following basis (ground limestone must be ground to a fineness that permits 100 per cent. to pass through a screen with 10 meshes to the linear inch, and at least 30 per cent. through a screen with 100 meshes to the linear inch):—

(1.) On ground limestone analysing 80 per cent. or more calcium carbonate a subsidy of $1 per ton shall be allowed.

(2.) On ground limestone analysing 70 to 80 per cent. calcium carbonate a subsidy of 75 cents per ton shall be allowed.

(3.) On ground limestone analysing 50 to 70 per cent. calcium carbonate a subsidy of 50 cents per ton shall be allowed.

(4.) On hydrated lime having a minimum content of calcium hydrate of 85 per cent. and of a fineness of texture comparable to that required in ground limestone a subsidy of $1 per ton shall be allowed.

(5.) On dry marl having a minimum content of 75 per cent. calcium carbonate and a fineness acceptable to the British Columbia Lime Committee and having less than 20 per cent. moisture a subsidy of $1 per ton shall be allowed.

(6.) On wet marl, that is marl with 20 per cent. or more moisture content, a subsidy may be allowed at the discretion of the Committee, and if allowed shall be on the basis of samples submitted.

Some limestone products, notably hydrated lime, are used in the preparation of many plant sprays, insecticides, and fungicides. Hydrate free from grit, which might give rise to undue wear in the spray-pumps, is desired for this purpose. Lime is also used as the base for certain chemical fertilizers.

Small amounts of limestone, shell, granite, and gravel, crushed to about 5 to 10 mesh, are used as poultry grit. Ground limestone is also used to a limited extent in supplying calcium requirements for poultry and other farm stock.

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Science and Experimental Farms Services (1940): Manures, Fertilizers and soil amendments—their nature, function and use—*Dom. of Canada, Dept. of Agr.*, Publication 585.

METALLURGY.

Limestone and lime are used by several metallurgical plants in the area, chiefly as a flux in smelting. The Tacoma copper smelter and the basic open hearth at the Seattle plant of the Bethlehem Steel Company consume the largest amounts. Impurities normally occurring in limestone are not actively detrimental in flux but merely dilute the active ingredient. The value of the lime or limestone is, therefore, based on the lime content of the product.

Smaller amounts of lime are used in the cyanidation of gold ores and in concentrating ores by flotation in and adjacent to the area.

PULP AND PAPER INDUSTRY.

Limestone and lime are widely used in the pulp and paper industry in the preparation of cooking-liquors for the extraction of lignins from wood and also in the preparation of solutions for bleaching pulp.

Much of the pulp in the Georgia Strait area is produced by the acid-sulphite process in which limestone, or lime, is commonly used. Cooking-liquor for this process is made from limestone in two ways, by the tower method or by the milk-of-lime method. About 300 lb. of limestone are consumed for every ton of pulp produced by the sulphite process.

In the tower method for producing cooking-liquor, limestone, in lumps greater than 5 or 6 inches in diameter, is treated in towers with a falling current of water and a countercurrent of sulphur dioxide gas. The product of the tower is a solution consisting of sulphurous acid, formed by the combination of water and sulphur dioxide, together with calcium bisulphite formed by the reaction of some of the sulphurous acid with the limestone. Insoluble residue from the limestone settles from the solution and is removed periodically, but carbon, mica, and pyrite are apt to float off with the liquor and contaminate the pulp. Magnesian limestone dissolves slowly, and if present in large amounts not only may reduce the output of the towers but also may form a spongy residue which crumbles and tends to choke the flow of the sulphur dioxide. Operators, therefore, desire a limestone containing not more than about 4 per cent. magnesia.

In the milk-of-lime process for producing cooking-liquors, sulphur dioxide is passed through an aqueous suspension of lime, of either the high-calcium or, preferably, the high-magnesium variety. Insoluble matter, carbon, mica, and pyrite are, as in the tower method, objectionable.

In the Kraft or sulphate process for the manufacture of pulp, wood is digested in an alkaline or "caustic" cooking-liquor. After digestion the cooking-liquor is separated from the pulp, evaporated, sodium sulphate is added, and the mixture burned to eliminate organic matter. The residue is leached with water, then causticized with lime, and after the sludge has been removed the alkaline cooking-liquor is left. In some places the sludge from the causticization stage has been burned to recover its lime content.

Bleaching solution for pulp is made from high-calcium lime and liquid chlorine. For this purpose the lime must have low magnesia and iron contents, and insoluble matter and unburned carbonate should be at a minimum. The lime, moreover, must be capable of both absorbing chlorine rapidly and of settling rapidly from a suspension.

Reference.

Rowley, H. J. (1939): Limestone in the pulp and paper industry—*Can. Inst. Min. and Met.*, Trans., Vol. 42, pp. 599–607.

OTHER USES.

Other uses for limestone and lime in the Georgia Strait area are in the manufacture of glass, in refining of sugar, in tanning of hides, and in the manufacture of bleaching powders and solutions for domestic use, etc.

References.

Goudge, M. F. (1929): Limestone in industry—*Mines Br., Canada,* Publ. 719, pp. 43–53.

——— (1939): Limestone as a raw material—*Can. Inst. Min. and Met.,* Trans., Vol. XLII., pp. 521–526.

Hodge, E. T. (1938): Uses, technology, and market of limestone and lime. Part III., Vol. II., Sec. III. of " Market for Columbia River hydroelectric power using northwest minerals "—*War Dept. Corps of Engineers, U.S. Army, North Pacific Division,* pp. 384–397.

CHAPTER III.—EXAMINATION OF CALCAREOUS DEPOSITS.

GENERAL.

Three factors are considered to be of prime importance in the evaluation of a limestone-deposit: size, grade, and accessibility to markets.

Although estimation of the total tonnage of a deposit may be possible in some cases, it may be impossible to determine the proportion of the deposit that is economically recoverable. Existing information may be inadequate, for example, to permit determination of the area from which overburden and impure rock can be removed economically to expose high-grade limestone. The scale and method of quarrying can, moreover, have a marked influence on the amount of material that may be recovered from any one deposit; hence in the case of an undeveloped deposit the estimation of quantity of available limestone is doubly difficult. However, to aid in a preliminary assessment of the size of deposits described in Chapter V., the writer has noted, where possible, the outcrop length and the width, or if determined, the stratigraphic thickness and attitude, together with information on the presence of igneous rocks and on the thickness of overburden.

The grade of limestone that can be produced from a deposit, like the amount available, may be difficult to determine, especially for undeveloped deposits. This is particularly true in the case of a large limestone body made up of interbedded high- and low-grade strata, where either the high-grade strata alone might be selectively quarried or the entire deposit quarried on a large scale to obtain a lower-grade product. A deposit might, moreover, be quarried by such a method that any included igneous rocks could be eliminated from the final product or by a method in which these rocks would be left in it.

In view of the significance of transportation in determining the cost to a consumer of a limestone product, accessibility of a deposit to its markets is also of prime importance. Cost of transportation from a deposit to market is determined not only by the distance, means of transport, etc., but also by the volume of material handled, and is hence subject to considerable variation. Cost of transportation may be difficult to assess in the case of undeveloped deposits where the initial cost, and cost of maintenance and depreciation of any transportation facilities that may have to be installed, and the amount of material to be handled, etc., is uncertain.

Other factors, in addition to the three given above, which may be of importance in the evaluation of a limestone-deposit include availability to supplies of water, power, and fuel, accommodation for labour, topography, climate, etc.

The final evaluation of any deposit is beyond the scope of the survey on which this publication is based. The writer has, however, attempted to include in the descriptions of individual deposits what he regards as considerations of economic importance, but has avoided presenting estimates of tonnage and costs, both of which might subsequently prove to be misleading. Analyses of samples taken during the course of the survey are, however, included, together with a note on the method of sampling followed in each case and whether igneous rocks, etc., had been excluded in sampling. It should be recognized that these analyses at best only approximate the grade of limestone that is being or can be produced from any deposit.

As the principles of the field-mapping of mineral deposits and of the recognition of certain features are widely known, they need no elaboration here. The recognition in the field of magnesian and calcium-rich limestone, and the principles of sampling are, however, less generally understood in spite of their economic importance. The following notes which may be of assistance in future studies of limestone-deposits are, therefore, included.

Moreover, as methods of chemical analyses may vary, notes by the Chief Assayer and Analyst of the British Columbia Department of Mines on the procedures used in the analyses quoted in this report have also been included.

FIELD RECOGNITION OF CALCIUM- AND MAGNESIUM-RICH LIMESTONE.

If it is possible in the field to recognize calcite and dolomite, the two essential minerals in limestone, and to determine the amounts of each, it becomes possible to estimate the chemical composition of the rock. Such estimates can be very useful, not only in prospecting for a limestone-deposit of suitable grade, but also in making preliminary assessments of the size and attitude of such a deposit. After considerable experience with comparisons of specimens and analyses, it may be possible to make these determinations with the unaided eye. The minerals can, however, be made more conspicuous by chemical tests and the estimates made more reliable. A comparison of the physical characters of calcite and dolomite and a description of two of the most useful field-tests are given below.

(1.) *Acid Etch.*—A common test for calcite and calcium-rich limestone is the application of cold dilute acid, commonly 1:5 hydrochloric acid. Calcite and calcium-rich limestone effervesce vigorously in such acid, whereas dolomite reacts feebly. This test, however, is in itself unsatisfactory since a small amount of calcite disseminated through magnesian limestone can give rise to an effervescence but little less vigorous than that of high-calcium limestone. If, however, a specimen of the limestone to be tested is immersed in the cold dilute acid for a period of from a half to one minute, then rinsed and dried, a characteristic texture is produced. Calcite and high-calcium limestone in this test develop a smooth glazed surface resembling that of vein-quartz or paraffin; insoluble minerals, including dolomite, which is almost unaffected by this treatment, retain the texture of the original surface and stand up in relief above the calcite (after Goudge, M. F.,* 1940, p. 484).

(2.) *Ferric Chloride—Ammonium Polysulphide Etch.*—A cold saturated solution of ferric chloride in water reacts with calcite within a half to one minute to produce a surface film of ferric carbonate. If calcite so treated is rinsed in water to remove excess ferric chloride and immersed in a solution of ammonium polysulphide, the reaction with the ferric carbonate film gives rise to a conspicuous black coating of ferric sulphide in the calcite. Dolomite remains almost unaffected, but longer immersion in ferric chloride permits the development of a weak ferric sulphide stain. Insoluble matter, silica, etc., do not respond to this test no matter how long they are immersed in ferric chloride. On drying, the ferric sulphide stain reverts to brown ferric carbonate (after Holmes, A.,† 1930, pp. 264, 265).

Other similar tests, most of them less applicable for field use, are given in standard texts on petrography. (*See* Holmes, A.,† 1930, pp. 265–268.) It should be emphasized that calcite, and the rarer calcium carbonate mineral aragonite, respond to the tests outlined above, but except with a prolonged etch, dolomite does not respond and cannot generally be distinguished from more completely insoluble minerals. Other characters, notably hardness, are necessary in determining the presence of dolomite.

Pure calcite consists of 56.1 per cent. lime (CaO) (100 per cent. $CaCO_3$), pure dolomite of 30.4 per cent. lime (54.3 per cent. $CaCO_3$) and 21.9 per cent. magnesia (MgO) (45.7 per cent. $MgCO_3$). A limestone composed, for example, of about 90 per cent. calcite and 10 per cent. dolomite, as indicated by tests and physical characters, would contain about 2.2 per cent. magnesia (4.6 per cent. $MgCO_3$); a limestone composed of about 10 per cent. calcite and 90 per cent. dolomite would contain about 19.7 per cent. magnesia (41.2 per cent. $MgCO_3$).

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* Goudge, M. F. (1940): Magnesia from Canadian brucite. *Can. Inst. of Min. and Met., Trans.*, Vol. XLIII.

† Holmes, A.: Petrographic methods and calculations. *Thomas Morby & Co., London*, revised 1930.

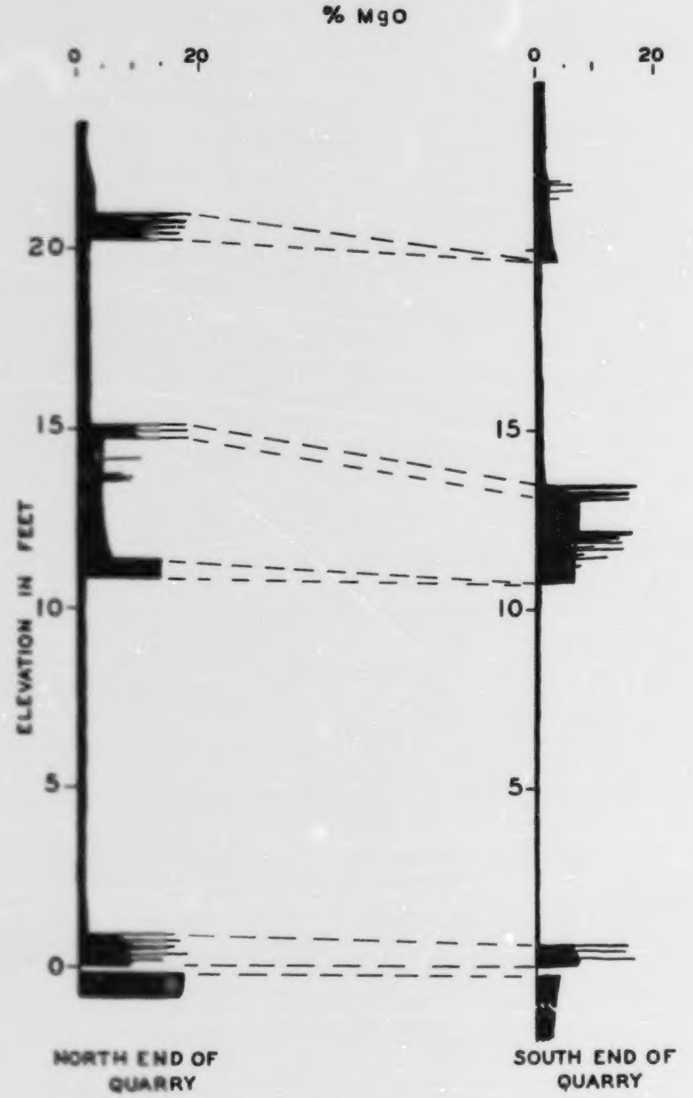
The character of the weathered surface also serves to distinguish calcium-rich and magnesium-rich limestone within the area studied. The period of post-Glacial weathering has been sufficiently long in the Georgia Strait area to permit the development on limestone of an etched surface somewhat similar, though on a much larger scale, to that obtained by immersion in acid. The weathered surface of a calcium-rich limestone presents a smooth outline, although, in the case of marble, rapid weathering along crystal boundaries, cleavage, etc., may give a minutely roughened texture. Joints in calcium-rich limestone are generally widely gaping. Small caves and pot-holes, usually a few inches wide, are common. Any dolomite grains and veinlets generally, but not invariably, stand up on the limestone surface in marked relief, as does silica and other insoluble material. Dolomitic limestone, on the other hand, is much more resistant to weathering and its surface commonly presents a more or less angular outline. Joints and solution cracks developed along calcite veinlets are deep and narrow, little if at all gaping. The outcrop, therefore, commonly presents a deeply but finely scored appearance brought about by numerous intersecting cracks. Silica and other insoluble material stand up above the dolomite surface, though with but little relief.

On recrystallization high-calcium limestone becomes marble. Any silica present or introduced may combine with the calcite to form white needles and fibres of wollastonite or tremolite disseminated through the marble. Dolomitic limestone, on the other hand, is less susceptible to recrystallization but apparently more susceptible to brecciation. Any silica present or introduced may combine with dolomite and other impurities to form olivine, serpentine, chlorite, diopside—all minerals tending to be yellow or green in colour. A yellow colour is also common but not diagnostic of dolomitic limestone which has not recrystallized. Dolomitic limestone likewise tends to be slightly harder and have slightly higher specific gravity than calcium-rich limestone.

SAMPLING.

If a limestone-deposit were of uniform composition throughout, a single chip would be a representative sample of the entire deposit. Very rarely, however, is limestone of uniform composition across more than a few feet of beds. As described above a limestone-deposit is composed of successive layers of strata of different composition. A sample of one of these strata may be representative only of that particular stratum. Studies, moreover, show that neither the thickness nor the composition of any stratum is identical over its entire extent, but both tend to change gradually from place to place (*see* Fig. 2 and table, page 29). Thus a sample of one stratum is representative only of that part of the stratum in the vicinity of the point sampled.

A grab sample, made up of a single chip taken at random, is almost certain not to be representative of a succession of limestone-beds. In the case of the Limekiln Bay quarry, for example, only two beds, one of argillite and an underlying bed of orange-weathering magnesian limestone, would have been readily distinguishable at the time of quarrying. Any single 6-inch cube taken at random from an apparently uniform succession above the argillite bed could contain from less than 0.58 to 13 per cent. magnesia, depending on which bed was sampled. Since, however, only 7 feet out of the 28.2 feet exposed at the north end of the quarry and only 4 feet out of 29.7 feet exposed at the south end of the quarry are composed of magnesian limestone, the odds are against the selection of such impure rock in a single grab sample and are in favour of the selection of a rock of somewhat higher grade than the average of the entire succession. In other cases, however, where impure beds predominate in the succession, the odds are in favour of a single grab sample containing more than the average content of impurities.



DISTRIBUTION OF MAGNESIA IN STRATA REPRESENTED DIAGRAMMATICALLY
LIMEKILN BAY QUARRY, TEXADA ISLAND

Fig. 2.

The size of a grab sample, moreover, is significant. In the case of the Limekiln Bay quarry a minute sample of the size of a single crystal in the limestone might consist either of a grain of dolomite containing more than 20 per cent. magnesia or a grain of calcite containing almost no magnesia. A sample the thickness of a single dolomitic lamina might likewise be composed almost entirely of either dolomite or calcite. On the other hand, no sample consisting of, say, a 5-foot cube, could contain more than 6.2 nor less than about 0.58 per cent. magnesia, and the odds are that it would contain much closer to the average amount, about 2.08 per cent. magnesia, of the entire succession above the argillite bed.

A fully representative sample of a succession of strata can be obtained in two ways, (1) by sampling the individual beds and computing the average of the succession, weighting each analysis according to the thickness of limestone it represents, or (2) by collecting across the full width of beds to be sampled the limestone chips cut by hand from a continuous channel of uniform depth and width, or the core from a diamond-drill hole of uniform diameter, or the dust and cuttings from an air- or churn-drilled hole, likewise of uniform diameter. It may be advantageous but is by no means necessary that the sample should be cut along a line at right angles to the strata, and in some cases it may be necessary to sample along a line cutting obliquely across the stratification, in which case, however, the stratigraphic thickness of the beds sampled is not the length of the line sampled.

An approximate sample can be made up from a series of chips of uniform size taken at regular intervals across the succession. Such samples can be obtained much more cheaply and readily than can continuous channel or drill samples, especially in the case of surface sampling of partly drift-covered areas in undeveloped deposits. This method, on the other hand, suffers from some of the shortcomings of grab-sample method in which, for example, by chance selection one chip from a very thin impure bed might be included in the sample and thus unduly contaminate it. In spite of this handicap this method was adopted in obtaining most of the samples analysed for this report.

Samples should be taken along one or more lines cutting directly or obliquely across the bedding. It should be readily apparent that if a series of chips or a channel were taken along a line parallel to the stratification they would be no more representative of a full succession of beds than would a single chip from one bed. In some cases, however, stratification is not apparent, and it is then necessary to assume that bedding is parallel to the length rather than the width of the deposit and then sample accordingly. In such a case, nevertheless, the uncertainty of the attitude of the bedding raises doubts as to the amount of limestone represented by the sample and reduces the significance of the resulting analysis.

THE CHEMICAL ANALYSIS OF LIMESTONE.

By G. C. B. Cave.[*]

GENERAL.

As details of procedures for the complete technical analysis of limestone are generally well known,[†][‡][§] the following notes will consist chiefly of comments on these procedures, with some attention to sources of error. This laboratory is always pleased to submit to interested persons detailed procedures of analysis. The analyses reported in this bulletin are "technical"; that is, they are routine analyses suitable for the economic evaluation of deposits. "Refined" analyses are more time-consuming, and are generally made only when the results are to be used for more theoretical studies.

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[*] Chief Analyst and Assayer, B.C. Department of Mines.

[†] Hillebrand, W. F.: Bull. U.S. Geol. Survey No. 700 (1919).

[‡] Mellor, J. W., and Thompson, H. V.: A Treatise on Quantitative Inorganic Analysis; Griffin & Co., Ltd., 42 Drury Lane, W.C. 2, London (1938); 2nd ed.

[§] Scott, W. W.: Standard Methods of Chemical Analysis, edited by N. H. Furman; D. Van Nostrand Co. Inc., 250 Fourth Ave., New York (1939); 5th ed., Vol. II., pp. 1600–1617.

Acid Insoluble Matter.—This assay is to some extent empirical. The percentage of acid insoluble matter usually depends on the following factors: fineness of grinding of the sample, strength and kind of acid or acids used for solution of the sample, the temperature and length of time of digestion of acid and sample. The procedure adopted for results in this bulletin was: to a 0.5-gram sample add 25 ml. water and 10 ml. hydrochloric acid (s.g. 1.19) and evaporate to dryness on a hot-plate. Reproducible results were obtained.

If the results are to be used for mineralogical studies, determination of silica rather than acid insoluble matter may be required.

R_2O_3.—R_2O_3 in this bulletin* comprises the oxides (ignited), except iron oxide, that are precipitated when the filtrate (oxidized if necessary) from the acid insoluble matter assay is made alkaline to methyl red on the addition of ammonium hydroxide. It therefore may include oxides of aluminium, titanium, zirconium, beryllium, chromium; quinquavalent phosphorus, quinquavalent arsenic, and quinquavalent vanadium. Any silica left in solution from the acid insoluble matter assay would also be precipitated. If insufficient iron, aluminium, etc., is present to combine with the phosphate (or arsenate) the remainder of this anion will be precipitated as a calcium salt, thus introducing a negative error into the calcium assay.

It is important to precipitate R_2O_3 at the proper pH. This lies between 6.5 and 7.5 for the complete precipitation of aluminium. At a higher pH the hydrated aluminium oxide partly dissolves because of its amphoteric nature. Further, sufficient ammonium chloride must be present prior to precipitation of R_2O_3 by ammonia, especially if magnesium is present. Long-continued boiling of the solution containing the precipitated R_2O_3 and long-continued standing of R_2O_3 in the mother liquor are prejudicial to good results. Indeed a double precipitation of R_2O_3 is to be recommended if the analysis is to have any degree of refinement. Washing of the R_2O_3 precipitate should be done with a hot 2-per-cent. solution of ammonium chloride or ammonium nitrate. Pure hot water will peptize the precipitate. Ignition and dessication of the R_2O_3 require attention. Ignition to constant weight at over 1,200° Centigrade is required. Ignited alumina, particularly, absorbs water, and should be dessicated for a minimum time and then weighed in a covered crucible.

Finally, the ammonium hydroxide solution used to precipitate R_2O_3 should be free of carbonate. Otherwise calcium carbonate would be precipitated along with the R_2O_3.

MnO (Total).—To decompose a limestone sample completely, advantage may be taken of the fact that a sintered mass, completely soluble in acid, is obtained on igniting the sample for 15 minutes at 1,100° Centigrade in a covered platinum crucible. For this procedure the silica present should not exceed 15 per cent. and the R_2O_3 should not exceed 5 per cent. To make this procedure applicable to all cases, especially to siliceous limestones and calcareous marls, this laboratory mixes one gram sample with 0.5 gram sodium carbonate, and sinters the mixture for 20 minutes at 1,100° Centigrade in a covered platinum crucible. The cooled sinter is then dissolved by treating with 10 ml. of water and 10 ml. nitric acid (s.g. 1.42). The manganese is then converted to permanganate by the well-known persulphate method. If much iron is present, phosphoric acid is added (it is also then added to the standard solutions). The depth of the permanganate colour is read in a photoelectric colorimeter and the readings converted to per cent. manganese oxide by the use of a graph previously set up from prepared standard manganese solutions.

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* *See* page 7 for explanation of chemical symbols.

There are definite indications that the periodate method of oxidizing the manganese is more convenient than the persulphate method, and a comparison of the two methods is at present being made at this laboratory.

Fe_2O_3 (Total).—This represents total iron in the sample, and to conform with custom is reported as the oxide. One gram of sample is mixed with 0.5 gram of sodium carbonate, and the mass sintered as in the manganese assay. The sinter is dissolved in dilute hydrochloric acid and the solution evaporated to dryness. Soluble salts are then dissolved by adding exactly 1 ml. hydrochloric acid (s.g. 1.19) and then 20 ml. water, and heating. Any silica is filtered and discarded if small in amount. The filtrate is assayed for iron by an original modification of the salicylate colorimetric method*†‡ and the depth of the purple colour is read on a photoelectric colorimeter. Good results have been obtained by this modified salicylate method, even though it is not a very commonly used procedure. Aluminium should not be present in amounts exceeding about 10 milligrams per 100 ml. of solution. Higher amounts cause a negative error in the iron result. As practically all samples analysed for this bulletin had less than 2 per cent. alumina, it did not interfere. Spectrographic analyses proved that other metals were not present in percentages that would cause interference.

Before applying the salicylate colorimetric method to other kinds of material, the analyst should be sure elements in detrimental amounts are absent, a fairly complete list of which is given in the literature.†‡

CaO.—The percentages reported in this bulletin are of acid-soluble lime, determined on the filtrate from the R_2O_3 assay. The calcium is precipitated as oxalate from an alkaline solution, the washed precipitate dissolved, and the oxalic acid titrated with standard permanganate. As voluminous literature exists on this method comments will be brief. When the percentage of calcium need not be known very exactly and where the magnesium in the sample is less than 5 per cent. one precipitation of calcium as oxalate will suffice. But the analyst should realize that the calcium oxalate will then be contaminated with alkalis, barium, strontium, magnesium, and manganese. Reprecipitation of the calcium as oxalate will remove the barium, if in the low percentages usually found, the alkalis, and not quite all the manganese. Strontium will be quantitatively reprecipitated with the calcium as oxalate. It should be remembered also that calcium oxalate is somewhat soluble in hot water, 100 ml. of which at 95° Centigrade dissolving 1.5 milligrams of calcium oxalate.

There have been objections to the filtration of calcium oxalate through paper, since in the subsequent titration the paper is usually added to the oxalic acid solution being titrated, whereupon the paper reduces permanganate slightly. To obviate this possible source of error, the precipitated calcium oxalate may be filtered through a Gooch crucible with an asbestos pad.

MgO.—The percentages reported in this bulletin are of acid-soluble magnesia, determined on the filtrate from the lime assay. The gravimetric 8-hydroxyquinoline method is used. Excellent checks were obtained between per cent. magnesium oxide determined by the classical phosphate method and by the more rapid 8-hydroxyquinoline method.

P_2O_5 (Total).—Solution is accomplished as follows: a large sample is dissolved in nitric acid, the insoluble residue is fused with sodium carbonate, the melt extracted with nitric acid, the solution evaporated to dryness and the silica dehydrated, and the soluble salts dissolved in dilute nitric acid. The two nitric acid solutions are then combined. The phosphorous is concentrated from this latter solution by adding ferric chloride and precipitating the phosphorous as iron phosphate, which is then dissolved in nitric acid. The phosphorous is then determined gravimetrically by the well-known

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* Snell, F. D., and Snell, C. T.: Colorimetric Methods of Analysis: D. Van Nostrand Co., Inc., New York (1936): 2nd ed., Vol. I., p. 301.

† Mehlig, J. P.: Ind. Eng. Chem., Anal. ed., 10, pp. 136-139 (1938).

‡ Scott, R. O.: Analyst, 66, pp. 142-148 (1941).

phosphomolybdate method. The phosphomolybdate precipitate is always dissolved and reprecipitated before weighing. Alternatively, the phosphate can be precipitated as magnesium ammonium phosphate, ignited to magnesium pyrophosphate, and weighed.

Many investigations have been carried out on the phosphomolybdate method, hence, only a few comments are necessary here. First, the composition of the yellow precipitate is variable, depending on such factors as temperature of solution at precipitation, length of time of standing of precipitate, concentration of reagents, and composition of the solution itself. Further, the phosphorous must be present as orthophosphate. Hence concentration of reagents, temperature, digestion time, and composition of the phosphate solution must be standardized.

Substances which if present would contaminate the phosphomolybdate precipitate include quinquavalent vanadium, arsenic, titanium, zirconium, and silicon. Titanium and zirconium, if present, may precipitate as phosphates earlier in the assay.

S (Total).—This is determined on a large sample, the sulphur being finally weighed as barium sulphate.

CHAPTER IV.—STRATIGRAPHY OF THE GEORGIA STRAIT AREA.

PALÆOZOIC ROCKS.

Palæozoic rocks are widely distributed throughout the western part of the Cascade Range (*see* plate in pocket). These rocks are composed for the most part of sheared sediments, including chert, quartzite, schistose argillite, and limestone lenses, together with tuffs, agglomerates, flows, locally pillow lavas, and structureless greenstones. The so-called old metamorphic series is evidently made up of rocks of widely differing ages, for fossils ranging from Ordovician (Smith, W. S., 1916)* to Pennsylvanian or Permian (Daly, 1912) have been found in various parts of the area. Because of the extreme complexity in the structure of these rocks and the apparent scarcity of readily recognizable horizons, no attempt has been made on any large scale to subdivide the series. It is evident, however, that Permo-Carboniferous rocks are widely represented, for fossils of this age have been found through the greater part of the Chilliwack series, more than 6,000 feet thick, outcropping along the 49th parallel (Daly, 1912), and other fossils of this age have been found in the area south-east of Granite Falls, Washington (Weaver, 1912). Crinoid stems, made up of stacks of calcite disks up to ¾ inch in diameter, are common in the Chilliwack series and in the Cache Creek series of similar age in the Interior of British Columbia, where stems of this size are not known to occur in the Mesozoic rocks. These stems may, therefore, be considered as strongly suggestive, although not necessarily diagnostic of an Upper Palæozoic age. Such stems in Cascade limestone were reported as early as 1896 (Walcott, pp. 53–55) and have been found in several of the Washington deposits.

The occurrence of Palæozoic rocks on and adjacent to Vancouver Island was first indicated by Richardson who, in 1872, collected fossils, identified as Permian or Carboniferous, from the limestones of Horne Lake and the Ballenas Islands (Richardson, 1873 and 1874). This identification was later questioned by Clapp (1912, p. 70) who favoured their inclusion in the Triassic. Gunning (1930, p. 59), however, later obtained a full collection of fossils, identified as Permian or Pennsylvanian, from the limestone of the Buttle Lake area. Upper Palæozoic forms were found by Sargent (1941, p. 19) in the area south of Buttle Lake and by Stevenson (1944, p. 144) in an area about 10 miles south-east of Alberni. In the locality south-east of Alberni the fossils were recovered from limestone bodies interbedded with or overlying a complex series including cherts, argillites, and limestone, tuffs, breccias, amygdaloids, pillow lavas, and structureless greenstones of either intrusive or extrusive origin, all more or less schistose, generally badly faulted and locally contorted. These rocks are lithologically similar to unfossiliferous schists, etc., first mapped and described in detail by Clapp (1912) as the Sicker series. This series is indicated by Clapp as extending with possibly some discontinuities from the vicinity of Alberni south-easterly to Mount Sicker, the type locality, and beyond to Saltspring and Moresby Islands (*see* Fig. 4), a total distance of 70 miles.

The San Juan Islands (*see* Fig. 4) of the State of Washington, which at the closest point lie 7 miles to the south-east of Moresby Island, are underlain by a thick series of similar schistose rocks in which fossils ranging from Upper Devonian to Upper Permian age have been found (McLellan, 1927) (*see* reference on page 51).

The rocks of Anderson Bay (McConnell, 1914), at the southern end of Texada Island, are lithologically similar to these Palæozoic rocks; they contain large crinoid stems such as are described above and underlie, apparently with a slight angular unconformity, known Upper Triassic rocks. These Anderson Bay rocks are, therefore, also regarded as Upper Palæozoic in age.

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* *See* references at end of chapter, page 39.

TRIASSIC ROCKS.

The Triassic rocks of Vancouver Island were first studied and described in detail by G. M. Dawson (1887). As a result of his investigations along the shores of the northern part of Vancouver Island and adjacent islands, he proposed a stratigraphic succession which to this day has not been superseded. His descriptions can, therefore, be quoted directly.

" By far the greater part of the area of the northern portion of Vancouver Island is occupied by rocks of volcanic origin, which at first sight, and as judged by Eastern American analogies, might often be supposed to represent formations occupying a very low stage in the geological scale. These volcanic rocks . . . have since been subjected to metamorphism more or less intense . . . and now form, for the most part, rocks which might be spoken of as 'traps' and 'greenstones.' . . .

" The greater part of this old volcanic series appears to have been built up of basaltic and trachytic [andesitic(?), *Ed.*] lava flows, alternating with rough volcanic breccias and tuffs, largely composed of fragments derived from such flows. These rocks are now represented by hard amygdaloids and agglomerates of general dark greenish colours, though often greyish and sometimes purplish or reddish; by felsites, more or less porphyritic, and by hard, regularly stratified ash-beds. . . ."

Dawson noted the widespread presence of " ropy " structure on the surfaces of flows and may have been referring to the pillow structure, undescribed as such in his day, which is common in this series.

Dawson adds: " In association with these volcanic rocks, limestones, argillites, and quartzites occur, possibly at several different horizons, but one of these, which is of considerable thickness and great persistency and possesses very distinctive characters, has now been recognized at a number of places, from the northern part of Georgia Strait around the north end of the island and in Quatsino Sound. This intercalated zone is of considerable thickness, having been estimated at 2,500 (feet) at one place on the north coast of the island, where it appeared to be fully displayed. Massive limestones form its lower portion. The upper part of the limestone becomes interbedded with argillites in regular flaggy layers, and black, flaggy argillites, interbedded with quartzites, overlie these. Where the top of this argillite series is seen it often holds tuffaceous and fine agglomeritic beds, and is followed, in ascending order, by a great thickness of the altered volcanic rocks. In other localities the limestone is found to become interbedded with volcanic materials beneath, and though no complete section of the entire series can be offered, it is quite clear, from observations made in a great number of places, that these sedimentary materials form an intercalation in the great volcanic series. . . .

"As a convenient distinctive name for the whole, I shall employ the term *Vancouver series*, including for the present under this name not only the entire mass of volcanic materials which unconformably underly the Cretaceous, but also the interbedded limestones and flaggy argillites and quartzites. If this great mass of rocks should eventually prove separable into Triassic and Carboniferous portions, I would suggest the retention of the name Vancouver series for the former."

Subsequently geological studies in the area, notably by O. E. LeRoy (1908), J. A. Bancroft (1913), R. G. McConnell (1914), V. Dolmage (1918), C. H. Crickmay (1928), and H. C. Gunning (1931), etc., have led to subdivision of the Vancouver series and fuller descriptions of its parts.

The lower part, probably more than 10,000 feet thick, chiefly massive volcanic rocks, pillow lavas, and scattered limestone lenses, has been described under the names Texada group (LeRoy, 1908), Valdes group (Bancroft, 1913), Texada porphyrites (McConnell, 1914), and Karmutsen volcanics (Gunning, 1931). None of the known limestone lenses in typical occurrences of the Texada formation are thick enough to be commercially valuable. Some of the main occurrences of limestone up to 2,500 feet thick, described by Dawson, were for a time considered to be Palæozoic and some Triassic, but subsequent discoveries of fossils have indicated that all are Triassic, and, as indicated by Dawson, presumably all of a single horizon. This limestone has been described in reports as the Marble Bay formation (LeRoy, 1908; Bancroft, 1918; McConnell, 1914), the Quatsino Limestone (Dolmage, 1918; Gunning, 1931), and the Open Bay group (Bancroft, 1913). The latter differs from the typical Marble Bay formation in being distinctly argillaceous, but is apparently a more or less distinct facies of the same stratigraphic horizon.

The upper part of the Vancouver series, made up of argillites, impure limestones, calcareous sandstones, quartzites, and in places interbedded andesites, has been described by Bancroft (1913) and Crickmay (1928) as the Parsons Bay group and by Gunning (1931) as the Bonanza group.

Fossils are, in general, sparingly distributed throughout the series. Dawson reports finding no fossils in these rocks except those of Triassic age, but the stratigraphic location of these discoveries are, however, not known.

Fossils from the lower Texada formation found by the writer in 1945 on the west shore of Texada Island, 1½ miles north-west of Davies Bay (*see* Fig. 14), have been identified by McLearn as: *Paratropites* sp., *Hannaoceras* sp., *Cœnothyris* sp., *Pecten* sp., and crinoid stems of the Karnian stage of the Upper Triassic.

Fossils reported by McConnell as found in the Marble Bay formation of Texada Island include *Pentacrinus* cf. *asteriscus* Meek, *Terebratula* sp., *Pleuromya?* sp., *Pinna* sp. Those found by the writer on Texada Island include *Lima?* sp., *Pecten* n. sp.?, indeterminate gastropods, corals, and an indeterminate ammonite, *Clionites?*. From the latter fossils the age is inferred as "probably Triassic." These rocks, however, overlie the Texada formation in which the Karnian fossils, already described, were found. Fossils found by Gunning at Open Bay have been identified by McLearn as *Hannaoceras (Polycyclus)*, *Trachisagenites*, *Tropites*, and probably *Discotropites* and *Arcestes*. They are described as an Upper Triassic fauna of probably later Karnian age, representing possibly the fauna of the *Trophites subbulatus* zone.

Fossils found in the upper Parsons Bay formation include *Pseudomonotis subcircularis* Gabb, two species of *Halobia*, *Monotes alaskana* Smith, a new species of Entolium, and several new ammonites. They have been described in considerable detail by Crickmay (1928), who considers the upper members as including some forms of Lower Jurassic age.

Rocks of the Vancouver series occur in the southern part of Vancouver Island where they consist for the most part of altered andesitic and basaltic volcanics, now greenstones, with scattered limestone lenses. The rocks here are much more strongly folded and faulted than in the northern part of Vancouver Island and on Texada Island. Fossils have been found in one of the limestone lenses within the volcanics, on the south shore of Cowichan Lake (Clapp, 1912, p. 68), which were at first identified as Lower Jurassic but subsequently were referred (*see* McCann, 1922, p. 29) to the Lower Noric (i.e., Upper Triassic, above the *Tropites subbulatus* zone of the Marble Bay formation and below the *Monotis subcircularis* zone of the Parsons Bay formation). The thick succession of greenstones in this part of the area bears a distinct lithologic similarity to the Texada formation, but unless the fossils described above have a wider range than hitherto recognized, vulcanism must have persisted to a distinctly later stage of the Triassic in Southern Vancouver Island than in other parts of the Georgia Strait area. The Vancouver volcanics in the southern part of Vancouver Island differ from the Texada formation, however, in the degrees of folding and, locally, of metamorphism. The limestone-deposits associated with these volcanics are, moreover, much thicker, more lenticular, and more complexly folded and faulted than those of the Texada formation, and hence for convenience are described in this report under the original name given them by Clapp (1912), the Sutton limestones.

Specimens of the Triassic fossil *Halobia* are reported from a series of angular, poorly sorted conglomerates or breccias, grits, shales, etc., known as the Haro formation, occurring at Davidson Head (*see* Fig. 4), the northernmost point of San Juan Island, Washington (McLellan, 1927). These rocks may be the equivalent of the Parsons Bay formation, and, if so, they represent the only occurrence so far established of the latter formation in or adjacent to the southern part of Vancouver Island.

The Cultus formation, a succession of argillites with associated sandstone, grit, and some conglomerate, outcrops in the eastern part of the Fraser Valley (*see* Fig. 3). One collection of fossils (Daly, 1912) has been discovered in this formation and has been identified as *Arniotites vancouverensis* Whiteaves and *Aulacoceras?* resembling *A. Carlottense* Whiteaves. Judging from these fossils and the lithology the Cultus formation may also correspond to the Parsons Bay formation.

MIDDLE JURASSIC TO RECENT SEDIMENTS AND VOLCANICS.

Stratified deposits, both sedimentary and volcanic, continental and marine, ranging in age from Middle Jurassic to Recent, cover parts of the Georgia Strait area, particularly in the vicinity of Georgia Strait itself, of Puget Sound, and of the Strait of Juan de Fuca. These Middle Jurassic to Recent deposits contain no large or high-grade calcareous deposits and effectively conceal from discovery and development any Palæozoic or Triassic limestone-deposits that may underlie them. The weakly resistant Tertiary sediments of this group underlie a lowland or coastal plain on which much of the agricultural and industrial development of the region has taken place. Most of the markets for limestone and limestone products lie within this coastal plain and, therefore, at a greater or less distance from the better sources of raw material.

Rocks of Middle and Upper Jurassic age, chiefly argillites, tuffs, agglomerate, flows, and conglomerate, are found in the Harrison Lake area near the eastern end of the Fraser Valley (*see* Fig. 3) (Crickmay, 1930, *a* and *b*) (Geol. Surv., Canada, Map 737A, 1943). The literature does not record the presence of limestone-deposits in these rocks.*

Sediments of Lower Cretaceous age, chiefly conglomerate, sandstone, shale, and pyroclastics are known to occur in the Harrison Lake area and in the north-western part of the San Juan Archipelago (Crickmay, 1930, *a* and *b*) (Geol. Surv., Canada, Map 737A, 1943) (McLellan, 1927). No limestone-deposits are known in these rocks.

A series of sediments of Upper Cretaceous age, chiefly shales, sandstones, conglomerates, in part of continental origin and coal-bearing, outcrop along the western shores of Georgia Strait as well as in the central part of Southern Vancouver Island. The basal conglomerates and sandstones of this series are locally calcareous (Richardson, 1878, pp. 168, 169) (Clapp, 1914, pp. 55, 56), but limestone-deposits approaching commercial size or grade are not known in these rocks.

A group of flows and pyroclastics, the Metchosin volcanics, with minor associated sediments, containing marine fossils identified originally as Upper and, more recently, as Middle or Lower Eocene age, outcrop on Vancouver Island close to the shores of the Strait of Juan de Fuca, and on the Olympic Peninsula (Clapp, 1917; Weaver, 1937; Park, 1942; Green, 1945). In the latter area the series contains lenses of limestone, some large enough to justify quarrying if the grade were sufficiently high.

The Metchosin volcanics in the northern part of the Olympic Peninsula grade upward into a succession of tuffs and shales, also of Eocene age, known as the Crescent formation.

Sediments of Eocene age underlie large areas in the Fraser and Nooksack Valleys and to the east of Puget Sound, as well as local areas within the Cascade Range. These sediments, consisting of sandstones, shales, and conglomerates, are chiefly continental in origin and locally contain coal-seams, but parts are of marine origin. An occurrence of an " impure marl-like material " in these sediments has been reported from a point about 8 miles north-west of Bellingham (Glover, 1935, p. 14), but no other calcareous deposits have been noted. Volcanic and hypabyssal igneous rocks are associated with the sediments in the vicinity of the Fraser Delta, and are Eocene or younger (Johnston, 1923).

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* In a personal communication H. C. Gunning has mentioned an occurrence of limestone on the western shore of Cascade Peninsula, on Harrison Lake, in rocks mapped as Upper Jurassic.

A succession of marine sediments of Oligocene and Miocene age outcrop along the southern shores of Vancouver Island, on the western, northern, and eastern shores of the Olympic Peninsula, and in local areas in the vicinity of Puget Sound. These sediments are made up for the most part of sandstones, commonly cemented by abundant calcite conglomerate, thin beds of sandy shale, and marl (Clapp, 1917).

Miocene volcanics, without any accompanying limestones, cover a limited area in the Cascade Range in Washington, west of Grotto and south of Gold Bar.

Quaternary volcanic rocks, likewise devoid of calcareous deposits, occur on Mount Baker in Washington and in the Coast Mountains near Squamish, B.C.

Quaternary sediments, chiefly of glacial and alluvial origin, cover large areas, particularly in lowlands of the Fraser Valley and Puget Sound regions. The glacial deposits, till, and associated outwash are the products of two periods of glaciation. Separating these glacial deposits are interglacial sands, gravels, silts, and clays. In one locality these interglacial silts contain a deposit of travertine which has been worked as a source of lime (see *McMillin Deposit*, page 108). Elsewhere these glacial and interglacial deposits are not known to contain accumulations of calcareous materials. Alluvial deposits are being laid down along the lower portions of the rivers and in the adjacent marine waters. Calcareous sandstone is reported from the mouth of the Fraser River (Johnston, 1921, p. 35). Post-Glacial lacustrine deposits are also known, of which one, at Cheam Lake (*see* page 108), is composed of marl which has been recovered for agricultural purposes.

INTRUSIVE ROCKS.

Very large areas of intrusive rocks, composed chiefly of granodiorite and quartz diorite, outcrop in the Coast Mountains of British Columbia, and similar large intrusives are found in the northern part of the Cascade Range of British Columbia and Washington and on Vancouver Island. Most of these intrusives are believed to be of Late Jurassic and Cretaceous age. They intrude rocks older than the Upper Jurassic and are unconformably overlain by Cretaceous sediments. A few smaller intrusives are found cutting the Upper Cretaceous rocks of the east coast of Vancouver Island, others cut the Eocene rocks of the south coast of Vancouver Island, and at least one large intrusive cuts Miocene volcanics in the Central Cascades. Clearly, therefore, two or more periods of intrusion can be recognized.

Smaller masses of basic intrusives are found. These include the ultrabasic intrusives of Northern Washington (Bennett, 1940; McLellan, 1927) and of Southern Vancouver Island (Clapp, 1917). Others are composed of diorite and gabbro and may be either basic borders to the granitic intrusives or independent stocks.

Basic dykes and sills are common in some of the older stratified rocks, as on Texada Island (*see* page 65). In some cases these may be feeders to immediately overlying volcanics, but in many cases they cut granitic rocks which themselves intrude these older stratified rocks, and the dykes and sills can therefore be referred to a significantly later period. Dykes of granitic composition are found generally in the vicinity of larger granitic masses and can be considered as apophyses of these masses.

Not all the areas mapped as being underlain by the larger granitic intrusives are necessarily devoid of limestone-deposits. As indicated before (*see* page 100), in some places roof pendants or large inclusions of any of the older rocks and composed in part or entirely of limestone may be present.

STRATIFIED ROCKS OF UNCERTAIN AGE.

The age and correlation of several areas of unfossiliferous stratified rocks remain uncertain. Some of these rocks, such as those of the Nitinat, Leech River, and Malahat formations of Southern Vancouver Island (Clapp, 1912), were studied prior to the establishment on palæontological evidence of the stratigraphic succession in the Georgia Strait area. The existing information on these rocks, moreover, is inadequate to permit any correlation with the formations whose age has been established, if indeed they correspond to any of these formations. Other areas of rocks, particularly those in the isolated roof pendants of the Coast Mountains, have a lithology such that they can be correlated on the basis of existing information with two or more units of the established succession. The degree of deformation and alteration within the roof pendants, moreover, adds to the problems of correlation. All the above-mentioned rocks should be mapped as of uncertain age until such time as they can be re-examined and can be reliably correlated on the basis of stratigraphic evidence with recognized formations, or dated on palæontological evidence.

Probably all the rocks indicated as of uncertain age are Mesozoic or older. With the exception of those in the central part of the Olympic Peninsula all are cut by granitic intrusives. Some of the rocks contain limestone-deposits and one unit, the Nitinat formation of Southern Vancouver Island, is composed essentially of limestone or its alteration products.

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CHAPTER V.—DESCRIPTIONS OF DEPOSITS.

INDEX MAPS.

The following notes, descriptive of calcareous deposits, are grouped according to the geological age of the deposits; the notes in each group are arranged geographically. The deposits in the Georgia Strait area are indicated on Fig. 20, and deposits in considerable parts of the area are indicated on Fig. 3 (page 49), Fig. 4, and Fig. 8 (facing page 61). Figs. 4 and 20 will be found in the pocket. An alphabetical index of deposits and properties only which are operating or are shown on the maps and referred to in some detail in the text begins on page 111. A list of Palæozoic deposits being operated, idle, or undeveloped is found on page 42.

PALÆOZOIC LIMESTONES.

GENERAL.

Limestones are found at several, perhaps many, horizons within the Palæozoic section, hence they show distinct variations in thickness, chemical composition, and other characters. Many of the occurrences are less than 100 feet thick and perhaps not more than a few hundred feet long. Several of the smaller deposits which have been worked are composed of high-calcium limestone, a few contain magnesian beds, some contain siliceous beds and nodules, and some are argillaceous. The better of the smaller deposits have been quarried as a source of stone for pulp-mills, smelter flux, glass, agricultural stone, builders' and chemical lime, etc. Thicker deposits occur at Buttle Lake where the upper horizon varies from 100 to 500 feet in thickness;[*] at Grotto, where the limestone bodies are from 100 to 250 feet thick;[†] at Kendall, where the limestone is about 400 feet thick (page 47); at Chilliwack River[‡] and Concrete (page 45), where they are about 600 feet thick; and at Horne Lake (page 58), at least 1,200 feet thick. Probably all of these thicker deposits, except perhaps those at Grotto, Wash., are Upper Palæozoic and many may belong to a single horizon. These deposits are in general somewhat siliceous although smaller high-grade parts may be found within them. Argillaceous beds are associated with the limestone of the Kendall and Concrete quarries. The latter deposits are being worked for cement rock in which the siliceous and argillaceous impurities in the amounts present are not detrimental.

The Palæozoic rocks have been subjected in most places to more or less intense deformation and, being composed in part of relatively incompetent thin-bedded argillaceous rocks and ribbon cherts, have been highly folded and faulted. Central Vancouver Island and the Chilliwack River district, however, are underlain by gently dipping Palæozoic rocks which have escaped severe deformation.

Some of the larger deposits of limestone, for example those of Buttle Lake and Chilliwack River, can be traced continuously for miles. Many of the smaller deposits are, however, lenticular, terminated by faults or squeezed to feather edges during folding.

Most of the Palæozoic limestone-deposits now being worked are in the Cascade Range and the San Juan Islands of the State of Washington. Those in the former area include both small, higher-grade deposits near the western edge of the area of Palæozoic rocks closest to markets, and large lower-grade deposits suitable for cement manufacture at, in general, greater distances from markets. In the San Juan Islands the limestone-deposits are relatively thin, but many are of relatively high grade. Of the Palæozoic deposits of British Columbia only three have been worked, two in the eastern part of the Fraser Valley for agricultural stone and one on Texada Island for ornamental stone.

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[*] Gunning, H. C. (1930): Buttle Lake map-area—*Geol. Surv., Canada*, Sum. Rept., Pt. A, pp. 56-78.

[†] Glover, S. L. (1936): Nonmetallic mineral sources of Washington—*Wash. Div. Geol.*, Bull. 33.

[‡] Daly, R. A. (1912): Geology of the North American Cordillera at the forty-ninth parallel—*Geol. Surv., Canada*, Mem. 38.

TABLE.

List of Palæozoic limestone-deposits being operated, idle, or undeveloped:—

WASHINGTON CASCADES.

Deposit.	Product.	Owner or Operator.	Status, December, 1915.
Grotto (Baring)*†	Cement rock	Northwestern Portland Cement	Operating.
Gold Bar	Limestone, lime	Consumers Lime Co.	Idle.
Granite Falls*	Limestone	Everett Lime Co.	Operating.
Granite Falls	Limestone	Everett Lime Co., etc.	Idle.
Bryant*	Limestone	J. A. Jack	Operating
Concrete*	Cement rock	Superior Portland Cement	Operating.
Wash. Portland Cement	Cement rock	Superior Portland Cement	Idle.
Maple Falls*	Limestone	Maple Falls Lime Quarry	Operating.
Kendall*	Cement rock	Olympic Portland Cement	Operating.
Balfour	Cement rock	Olympic Portland Cement	Idle.
Northwestern Portland Lime		Olympic Portland Cement	Idle.

BRITISH COLUMBIA CASCADES.

Deposit.	Product.	Owner or Operator.	Status, December, 1915.
Chilliwack River*			Undeveloped.
Popkum*	Limestone		Idle.
Agassiz Lime Quarry*	Limestone	H. Cutler & Son	Operating.

SAN JUAN ISLANDS.

San Juan Island.

Deposit.	Product.	Owner or Operator.	Status, December, 1915.
Roche Harbor*	Limestone, lime, hydrate	Roche Harbor Lime & Cement Co.	Operating.
Cowell*	Limestone	Olympic Portland Cement	Operating.
Mitchell Bay	Limestone	Puget Sound Pulp & Timber Co. and Mitchell Bay Co.	Idle.
Mosquito Pass	Lime (?)	Orcas Lime Co.	Idle.
Limestone Point	Limestone	Puget Sound Pulp & Timber Co.	Idle.
Rocky Bay	(?)	(?)	Idle.
Sportsman's Lake	(?)	(?)	Idle.

Orcas Island.

Deposit.	Product.	Owner or Operator.	Status, December, 1915.
West Sound*	Limestone	Roche Harbor Lime & Cement Co.	Operating.
Red Cross Lodge*	Limestone	Roche Harbor Lime & Cement Co.	Idle.
McGraw-Kittinger*	Limestone	Westerman Lime & Rock Quarry	Idle.
Orcas Knob*	Lime	Orcas Lime Co.	Idle.
Orcas Knob	(?)	J. Sodberg	Idle.
Orcas Knob	Lime (?)	Imperial Lime Co.	Idle.
North-east Coast	(?)	(?)	Idle.
Langdon Ledge	Limestone	Tacoma Smelter	Idle.
Payton Ledge	(?)	Mount Constitution	Idle.

Cliff Island.

Deposit.	Product.	Owner or Operator.	Status, December, 1915.
Cliff Island	Limestone	Manufacturers Mineral Co.	Idle.

Henry Island.

Deposit.	Product.	Owner or Operator.	Status, December, 1915.
Henry Island	Limestone	Roche Harbor Lime & Cement Co.	Idle.

* Report appended.

† Temporarily idle for winter months.

VANCOUVER ISLAND.

Deposit.	Product.	Owner or Operator.	Status, December, 1945.
Raymond	Lime, limestone	Raymond & Sons	Idle.
Cobble Hill	Limestone	N. K. Bonner	Developing.
Mount Brenton			Undeveloped.
Schooner Bay			Undeveloped.
Anderson Bay	Ornamental stone	Continental Marble Co. and Malaspina Marble Quarries Co.	Idle.
Horne Lake			Undeveloped.
Buttle Lake			Undeveloped.

WASHINGTON CASCADES.

BARING DEPOSITS.

Location and Accessibility.—The Baring limestone-deposits are situated on the south wall of the Skykomish Valley, west of Grotto. They lie in Sections 13, 24, and 25, Township 26 north, Range 10 east. Grotto, a station on the Great Northern Railway, is 48 miles from tide-water at Everett. Grotto is also served by U.S. Highway 10A.

Geology.—The limestone-deposits are reported (Div. of Geology, Wash., Bull. 33) to be several hundred feet long and from 100 to 250 feet wide and to occur in a series of metamorphic rocks intruded by granodiorite and basic dykes.

Development and Operation.—The deposits are being worked by the Northwestern Portland Cement Company, of Grotto. Limestone has been quarried from a point 9,000 feet west of Grotto at an elevation of about 2,500 feet above sea-level, and is transported to the cement plant by aerial tram. The operations at the quarry are suspended during the winter months because of heavy snowfall. Surplus rock quarried during the summer is stock-piled at the cement plant and used during the winter as required.

The company is reported to be opening a new quarry south-east of the present quarry.

Clay for the cement plant is reported to be obtained from Brennan, Wash. (near Bellingham).

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Hodge, E. T. (1938): Market for Columbia River hydroelectric power using northwest minerals, Sec. III.—Northwest limestones—Vol. 1—*War Dept., Corps of Eng., North Pacific Div.*

GOLD BAR DEPOSITS.

Location and Accessibility.—A limestone-deposit is reported in Section 16, Township 27 north, Range 9 east, on Proctor Creek, a tributary of the Skykomish River, about 3 miles south-east of Gold Bar. Gold Bar is on U.S. Highway 10A and the Great Northern Railway, and is about 30 miles from tide-water at Everett.

Geology.—The quarry was not visited by the writer and the reader is referred to the report by Hodge* for information on the deposit.

Development and Operation.—This deposit has been worked in recent years by the Consumers Lime Company, of Gold Bar, Wash., but was idle in December, 1945. A mill near Highway 10A, 1 mile north of the deposit, consisting of a 10- by 18-inch Reliance jaw-crusher and a Gruendler mill, all powered by an 80-horse-power Fairbanks-Morse marine Diesel engine, has been used to grind the limestone. Lime is reported to have been produced by the company but no kiln exists at the site of the mill.

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* E. T. Hodge (1938): Market for Columbia River hydroelectric power using northwest minerals, Sec. III.—Northwest limestones—Vol. 1—*War Dept., Corps of Eng., North Pacific Div.*

GRANITE FALLS DEPOSITS.

Main Deposit.

Location and Accessibility.—The Granite Falls deposit of the Everett Lime Company is situated on the Monte Cristo Highway about 2½ miles north-east of Granite Falls. It lies near the centre of Section 5, Township 30 north, Range 7 east. The deposit is about 10 miles by road from the Northern Pacific Railway at Hartford or Getchell and about 20 miles by road from tide-water at Everett.

Geology.—Limestone in this deposit has been exposed along a belt about 200 feet wide and more than 500 feet long trending north-westerly across the north-eastern slope of a low hill in the valley of the south fork of the Stilliguamish River. Apparent bedding strikes north-westerly and dips at about 65 degrees south-westerly. The limestone is underlain on the east by a steeply dipping iron-stained schist. The western limit of the deposit is concealed by glacial till and by fluvioglacial gravels. Considerable faulting is in evidence, and for this reason the eastern contact of the limestone is distinctly irregular.

Only one clearly defined dyke was observed in the quarries, but irregular masses of iron-stained schist near the south-eastern end of the deposit may represent either intrusives or fault-blocks of older rocks.

Overburden is locally as much as 10 to 15 feet deep, and the north-western end of the deposit passes beneath terraced gravels of undetermined depth.

The limestone is moderately fine-grained and light cream in colour. A considerable part of the rock is distinctly magnesian.

Development and Operation.—This deposit has been operated since some time prior to 1936 by the Everett Lime Company. The Hadelgo Lime & Rock Company is reported to have also operated a part of this deposit.

Rock is now being shovelled by means of a ½-yard shovel into trucks and hauled to pulp-mills at Everett.

Other Deposits.

Other limestone-deposits in the vicinity of Granite Falls are reported to occur in the southern part of Section 9, Township 30 north, Range 7 east, now practically if not completely exhausted, and the North-west Quarter of Section 14, Township 30 north, Range 7 east.

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Glover, S. L. (1936): Nonmetallic mineral sources of Washington—*Wash. Div. Geol.*, Bull. 33, pp. 58, 59.

Hodge, E. T. (1938): Market for Columbia River hydroelectric power using northwest minerals, Sec. III.—Northwest limestones—Vol. 1—*War Dept., Corps of Eng., North Pacific Div.*

BRYANT DEPOSIT.

Location and Accessibility.—The Bryant or "Jack" limestone-deposit is situated on the north bank of the north fork of the Stilliguamish River 6 miles north-east of Arlington. It lies in the western part of Section 16, Township 32 north, Range 6 east. It is 7½ miles by gravelled road from the Northern Pacific Railway station of Bryant. The easternmost mile of this road, overlooking the Stilliguamish River, is steep and narrow.

Geology.—The deposit consists of a north-westerly-trending bed of limestone dipping steeply north-eastward and from 40 to 60 feet thick. It is bounded on the west by greenstone and on the east by graphitic schist. Both the limestone-schist contact and the schist itself are irregular and locally contorted.

No dykes were observed and overburden is slight.

The limestone is moderately fine-grained, blue in colour but traversed by a network of fine white veinlets which give the rock a mottled appearance. The rock is apparently of high grade.

Development and Operation.—The quarry has been operated since about 1941 by J. A. Jack, R.T. 4, Arlington, Wash. The quarry-face has been advanced in this time from the original outcrop along the strike of the bed into the river-bank for about 100 feet. As the hillside rises steeply from the river, the quarry-face is now about 100 feet high.

Rock is shovelled by a ½-yard Bucyrus shovel and transported a few feet to a small grinding plant consisting of a 12- by 9-inch jaw-crusher and a hammer-mill having a capacity of about 20 tons a day. It is planned to increase the capacity of the plant by installing a larger crusher and mill capable of grinding from 50 to 100 tons daily.

About 4,000 tons of limestone a year are being shipped from the deposit, chiefly to the Northwestern Glass Company, of Seattle, and to local farmers. Formerly rock was being shipped from this quarry to pulp-mills, but shortage of labour during the war limited production.

CONCRETE DEPOSITS.

New Concrete Quarry.

Location and Accessibility.—The Concrete quarry of the Superior Portland Cement, Incorporated, is situated 1 mile north-east of the town of Concrete in the southern part of Section 2, Township 35 north, Range 8 east, at an elevation of about 500 feet above sea-level. Concrete lies on the Burlington to Rockport branch of the Great Northern Railway, a distance of 44 miles from tide-water at Anacortes.

Geology.—The Concrete quarry lies in a series of limy, argillaceous, and siliceous sediments, striking north-westerly and dipping rather regularly at about 50 degrees north-eastward. A section of these sediments about 600 feet in stratigraphic thickness, consisting chiefly of massive limestone in the upper and lower parts separated by distinctly bedded argillaceous and siliceous limestone in the central part, is exposed on the quarry-face. Some green schist, possibly a tuff, outcrops in the uppermost part of the section at the eastern end of the quarry. One steeply dipping fault apparently of relatively small displacement is evident near the west end of the quarry.

No intrusives were noted in the quarry.

Overburden is shallow or wanting.

The limestone is variable in character, ranging from light grey in some of the purer beds to dark grey or black in the more argillaceous beds and varying from about 60 to 90 per cent. $CaCO_3$. The limestone is moderately crystalline. Some large crinoid stems can be found in parts of the quarry.

Development and Operation.—The quarry has been operated for about twenty years by Superior Portland Cement, Incorporated, of Seattle. The quarry was started on the north face of a knoll and has been worked southerly along the strike of the beds for as much as 500 feet. The present face is about 1,000 feet long and up to 360 feet high. Very large quantities of rock remain above quarry-level on the knoll.

The quarry is worked in benches 150 feet high. These are drilled with an 8-inch well-drill at 30- to 35-foot intervals 30 to 35 feet back from the face to the full depth of 150 feet. Breast-holes and lifters are drilled at the base of the face to depths of 30 feet by means of wagon drills. Approximately 200,000 tons of rock are brought down in a single blast. Some secondary blasting is necessary.

The rock is loaded by a 4-cubic-yard and a 2-cubic-yard shovel onto 12-ton capacity standard-gauge railroad-cars which are hauled to the crushing plant.

The rock from the quarry is dumped into a 42-inch Traylor gyratory crusher, powered by a 250-horse-power electric motor, and is broken to about 10 inches. It is elevated into a surge bin, then discharged into any of four 10-inch Gates gyratory crushers where it is broken to about 3 inches. Crushed rock is then conveyed on a belt conveyor to the head of an aerial tram-line, 1⅛ miles in length, and transported in 1½-ton buckets to the cement plant at Concrete. The capacity of this crushing plant and tram-line is about 1,900 tons per 8-hour shift.

At the cement plant the rock is sampled and stock-piled. Mixes of the desired composition are made up from this stock-pile and submitted to the cement plant. Although various parts of the quarry-face show considerable differences in composition, the bulk product of the quarry approximates that desired for the types of cement produced. A surplus of siliceous material is shipped to the Seattle cement plant of the same company.

Old Concrete Quarry.

An old quarry of the Superior Portland Cement, Incorporated, lies on the steep hillside about a ½ mile east of the currently operating Concrete quarry. This deposit was worked by a glory-hole, the rock lowered by an incline to the valley-bottom and transported by rail to Concrete. This operation has been abandoned for many years, and the site of the former railway has been flooded following the construction of a dam and power-plant on the Baker River.

References.

Glover, S. L. (1936): Nonmetallic mineral sources of Washington—*Wash. Div. Geol.*, Bull. 33, pp. 57, 58.

Hodge, E. T. (1938): Markets for Columbia River hydroelectric power using northwest minerals, Sec. III.—Northwest limestones—Vol. 1—*War Dept., Corps of Eng., North Pacific Div.*

Shedd, S. (1913): Cement materials and industry in the State of Washington—*Wash. Geol. Surv.*, Bull. 4, pp. 220–222.

MAPLE FALLS LIMESTONE-DEPOSIT.

Location and Accessibility.—The Maple Falls limestone-deposit is situated 2½ miles east of Maple Falls near the south-west corner of Section 22, Township 40 north, Range 6 east. It lies on the west bank of Boulder Creek about 1,000 feet in elevation above the north fork of the Nooksack River. Two miles of mountain road lead to the quarry from a point on the Mount Baker Highway 2 miles east of Maple Falls. Loading facilities on the Bellingham to Glacier line of the Chicago, Milwaukee & St. Paul Railway have been erected at this point. The rail haul to tide-water at Bellingham is about 40 miles.

Geology.—Quarrying was begun on what was apparently a pinnacle of limestone projecting through glacial drift. No exposures of bed-rock were observed in the immediate vicinity of the quarry, but limestone is reported to occur along the banks of Boulder Creek for as much as 1 mile north-easterly from the quarry. Serpentine boulders are locally plentiful in the drift overlying the limestone at the quarry.

One 2-foot dyke(?), now green schist, is exposed in the quarry.

Overburden is deep, locally exceeding 40 feet.

The limestone is white to grey in colour and moderately crystalline. Locally it is brecciated and healed with fine dark-coloured veinlets of insoluble matter which gives the rock a mottled appearance. The rock is, however, apparently in general of high grade. Large crinoid stems, similar to those occurring in other Palæozoic limestones, were observed in the quarry.

Development and Operation.—The deposit is being worked by the Maple Falls Lime Quarry. Two contiguous quarries, each about 75 feet in diameter, have been developed. About 30 feet of limestone is exposed in the present faces, overlain by 30 to 40 feet of overburden.

The quarry is equipped with one shovel of ¾-yard capacity. Rock is loaded onto trucks and hauled the 2 miles to the railroad siding.

Most of the limestone is being sold as pulp rock.

COLUMBIA VALLEY DEPOSITS.

Kendall Limestone Quarry.

Location and Accessibility.—The Kendall quarry of the Olympic Portland Cement Company is located on the east side of Columbia Valley, 2½ miles north of Kendall, at an elevation of 1,700 feet. It lies near the centre of Section 14, Township 40 north, Range 5 east. A spur from the Bellingham to Glacier line of the Chicago, Milwaukee, St. Paul & Pacific Railway extends to the east wall of Columbia Valley, 1,000 feet below the quarry. The distance from this point to tide-water at Bellingham is 34 miles.

Geology.—The quarry is situated in a succession of argillites and limestone which may be referred to the Permo-Carboniferous Chilliwack series. The strata trend north-easterly and dip at about 50 degrees south-eastward into the hillside. Argillites predominate near the point where quarrying was initiated, but as the face was advanced into the hillside, stratigraphically higher beds, in which limestone predominated, were encountered. At the present time the central part of the quarry-face, except at its base, is free from argillite.

Development and Operation.—This quarry was originally operated by the International Lime Company, but prior to 1928 was taken over by the Olympic Portland Cement Company, of Bellingham, who installed the present crushing system and tramway.

The quarry is at present being operated in a series of curved benches, 40 feet high and about 1,000 feet long. At its highest point the quarry-face rises about 230 feet above the floor. The company is planning to convert its quarry to a single face, eliminating the 40-foot benches, to use well-drill blast-holes, and to work southerly along the hillside on the strike of the limestone-bed now exposed in the quarry.

At present broken limestone is shovelled by means of a 100B Bucyrus 3-yard electric shovel into Easton TR-13 rubber-tired side-dump semi-trailers having 17 tons capacity and towed by Mack tractors to the crushing plant, where the limestone is broken to about 6- to 8-inch size in a 42-inch Allis-Chalmers gyratory crusher. The broken rock passes through a surge bin and over a pan feeder to a 7-foot Symons cone crusher where it is broken to about 1½ inches in diameter, in which form it is shipped to the Bellingham cement plant. The rock is conveyed by a two-span gravity aerial tram to the railroad spur at the foot of the hillside. The capacity of the crushing plant is about 250 tons an hour.

The grade of rock approximates that required for cement manufacture, but additional silica obtained from a quarry 3 miles west of the Kendall quarry (North-east Quarter of the North-west Quarter of Section 17) and clay from the vicinity of the Bellingham cement plant are also used.

Other Deposits.

Other quarries owned by the Olympic Portland Cement Company in this vicinity include the old quarry ¾ mile south-west of the present quarry at the base of the hillside near the north-west corner of Section 23, and the Balfour quarry on the opposite side of Columbia Valley in the North-east Quarter of Section 28. The former quarry, originally intended to be operated by the old Northwestern Portland Lime Company, may be on the continuation of the same limestone-belt which is at present being worked by the Olympic Portland Cement Company. Neither of these two quarries have been operated since 1929.

References.

Anon. (1929): Novel limestone quarry operation (New crushing plant of Olympic Portland Cement Company)—Rock Products, Vol. XXXII., No. 24, pp. 49–53.

Glover, S. L. (1936): Nonmetallic mineral sources of Washington—*Wash. Div. Geol.*, Bull. 33, p. 59.

Hodge, E. T. (1938): Market for Columbia River hydroelectric power using northwest minerals, Sec. III.—Northwest limestones—Vol. 1—*War Dept., Corps of Eng., North Pacific Div.*

Shedd, S. (1913): Cement materials and industry in the State of Washington—*Wash. Geol. Surv.*, Bull. 4, pp. 208–212, 215–217.

BRITISH COLUMBIA CASCADES.

CHILLIWACK RIVER.

Location and Accessibility.—Limestone outcrops at many points in the Chilliwack River Valley (Daly, 1912, and Map 89A, Geol. Surv., Canada), but probably the most accessible deposit is situated on a bluff or steep-sided knoll rising to an elevation of about 700 feet above the river immediately west of the mouth of Sleese Creek. This point, 13½ miles by road easterly from Vedder Crossing and about 16 miles from the British Columbia Electric Railway at Sardis, is in the North Half of Section 29, Township 1, Range 28, west of the 6th meridian. An old logging-railway grade, converted during 1945 into a road suitable for army vehicles, passes the base of the knoll.

Geology.—Limestone at least 200 feet thick is exposed on the steep side of a knoll of which the top is covered by overburden. On precipitous slopes lower on the knoll limestone at least 100 feet thick is exposed but is almost inaccessible. A belt of greywacke and argillite separates the two exposures of limestone. Whether the two exposures of limestone are parts of one body, repeated by faulting, or whether two separate bodies are present remains uncertain. The limestone strikes north 50 degrees east and dips from 10 to 35 degrees south-eastward. Chert beds are present, especially in the upper limestone exposure. No intrusives were observed.

Analyses.

	Insol.	R_2O_3.	Fe_2O_3.	MnO.	MgO.	CaO.	P_2O_5.	S.	Ig. Loss.	H_2O.
Upper limestone—										
Upper 100 feet	15.1	0.47	0.42	0.05	2.50	43.6	0.03	0.06	37.8	0.06
Lower 100 feet	22.5	2.12	0.91	0.63	0.82	40.1	0.07	0.03	33.2	0.07
Lower limestone	17.8	0.97	0.64	0.13	0.36	43.7	0.09	0.09	35.9	0.11

Development and Operation.—No development has been attempted on this deposit and, as it is now included in the Chilliwack Valley military reserve, it is no longer available for exploitation. Impurities in the limestone render it suitable only for agricultural stone or cement rock. The distance from good transportation facilities and to markets is detrimental. The steepness of the slopes on the lower part of the deposit, and the difficulty of access of the upper part would, moreover, entail great expense in the initial development of any quarry at this site.

Reference.

Daly, R. A. (1912): Geology of the North American Cordillera at the forty-ninth parallel—*Geol. Surv., Canada*, Mem. 38.

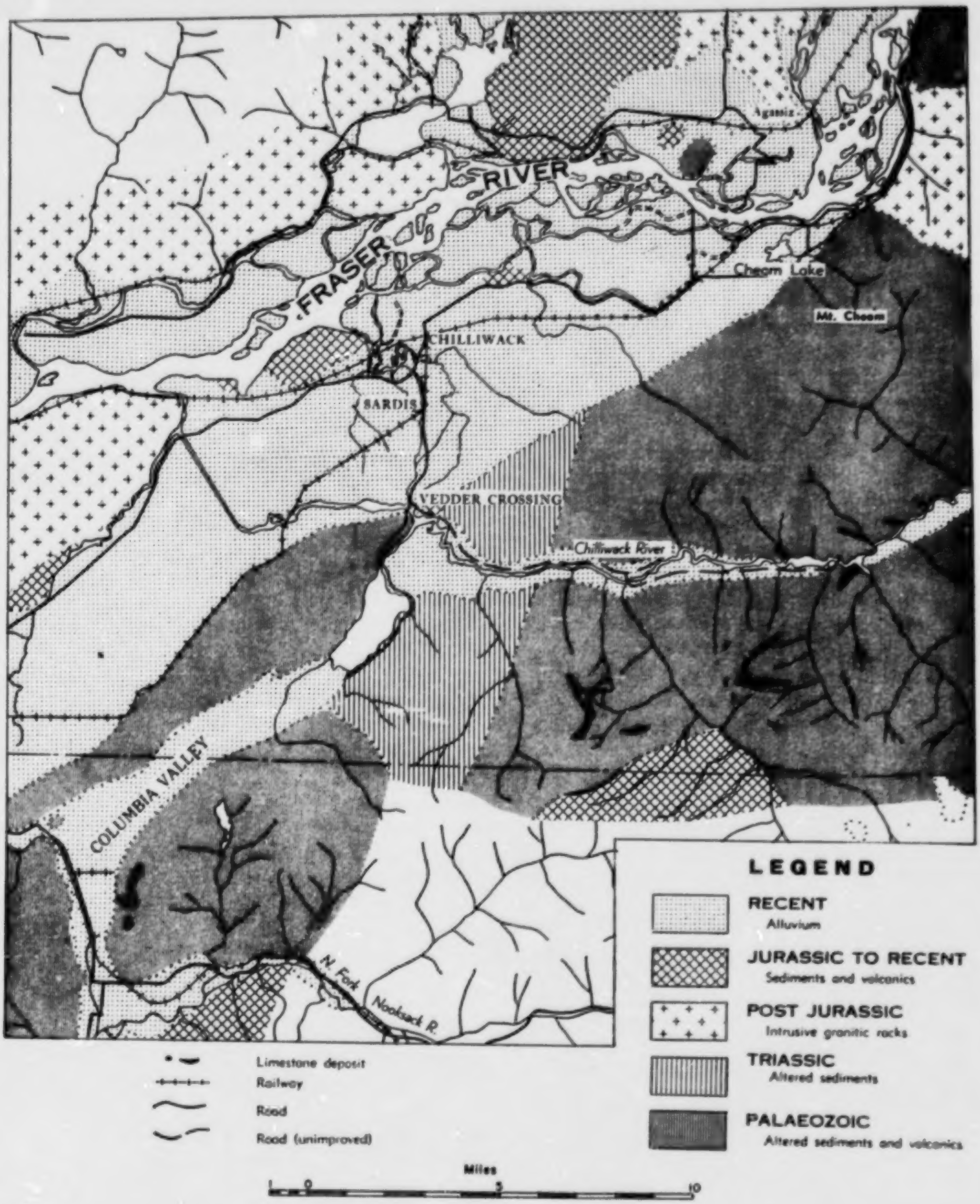
FRASER RIVER
Agassiz
Cheam Lake
Mt. Cheam
CHILLIWACK
SARDIS
VEDDER CROSSING
Chilliwack River
COLUMBIA VALLEY
N. Fork Nooksack R.
LEGEND
RECENT
Alluvium
JURASSIC TO RECENT
Sediments and volcanics
POST JURASSIC
Intrusive granitic rocks
TRIASSIC
Altered sediments
PALAEOZOIC
Altered sediments and volcanics
Limestone deposit
Railway
Road
Road (unimproved)
Miles
1
0
5
10

Fig. 3. Eastern Fraser Valley—geology and limestone-deposits.

POPKUM DEPOSIT.

Location and Accessibility.—The Popkum limestone-deposit is situated on the south side of the Fraser Valley at the base of Mount Cheam, approximately 12 miles east of Chilliwack. It lies in Section 9, Township 3, Range 28, west of the 6th meridian. The quarry lies within a quarter of a mile of the Cariboo Highway and about a mile and a half by road from Popkum Station on the Canadian National Railway.

Geology.—The limestone occurs as a bed at least 80 feet thick. It is overlain by argillite but the base is concealed by drift. Stratification in the rocks strikes northerly and dips about 15 degrees eastward. The extension of the limestone north-easterly and south-westerly across the mountain-side is concealed by drift. No intrusives occur in the exposures in the quarry.

Analyses of the limestone are as follows:—

	Insol.	R_2O_3.	Fe_2O_3.	MnO.	MgO.	CaO.	P_2O_5.	S.	Ig. Loss.	H_2O.
Top 50 feet	16.1	0.31	0.17	0.017	0.38	45.6	0.03	0.088	37.1	0.09
Lower 30 feet	14.7	0.03	0.10	0.013	1.18	46.0	0.03	0.090	38.0	0.05

Development and Operation.—The deposit now abandoned has been held and operated by the Western Canada Lime Company and the Popkum Lime Company, both of which have now been struck off the records of registered companies for the Province of British Columbia. A quarry up to 140 feet wide has been worked south-easterly into the mountain-side for a distance of about 50 feet. Because of the steepness of the surface, the face of the quarry has reached a height of about 100 feet at its centre and the argillites overlying the limestone have been exposed. The limestone was trammed along a narrow-gauge railway to a mill 500 feet north-west of the quarry. There the rock was passed through a gyratory crusher, mill, and screens. The crushing plant was powered by two 1-cylinder reciprocating steam-engines. Some work would be necessary to bring the plant into operating condition.

Any additional advance in the quarry-face would expose a still greater proportion of argillite and further reduce the grade of rock quarried. Extension of the quarry north-eastward or south-westward along the base of Mount Cheam would involve a greater or less amount of stripping of material fallen from above. Further extraction would, therefore, almost certainly necessitate underground mining. The rock itself contains so much insoluble matter as to be suitable only for cement or agricultural stone.

Reference.

Goudge, M. F. (1930): Preliminary report on the limestone of British Columbia—*Mines Br., Canada,* Inv. Min. Res., 1929, pp. 54–64.

AGASSIZ LIMESTONE-DEPOSIT.

Location and Accessibility.—The Agassiz limestone-deposit is situated at the south-eastern base of a hill projecting through Recent flood-plain sediments on the north bank of the Fraser River 2 miles south-west of Agassiz, B.C. It lies near the south-eastern corner of Section 23, Township 3, Range 29, west of the 6th meridian.

Geology.—The deposit consists of a lens of limestone about 40 to 70 feet across exposed on the south-western part of a knoll 50 to 100 feet high at the south-eastern base of the hill referred to above. The limestone strikes north 25 degrees east and dips from 35 to 60 degrees south-eastward. It is overlain by grey massive siliceous tuff or impure quartzite and underlain by greenstone of uncertain origin. The limestone-deposit narrows towards the south-west and disappears beneath drift close to the north bank of the Fraser. To the north-east on the top of the knoll it disappears beneath a cover of drift probably only a few feet thick.

The analyses of the limestone are as follows:—

	Insol.	R_2O_3.	Fe_2O_3.	MnO.	MgO.	CaO.	P_2O_5.	S.	Ig. Loss.	H_2O.
Top 20 feet	17.3	18.20	0.64	0.08	0.54	28.1	0.04	0.18	35.2	0.09
Middle 20 feet	18.2	2.56	0.76	0.07	0.62	43.6	0.04	0.28	33.8	0.06
Lower 30 feet	12.8	2.10	0.67	0.17	0.82	46.0	0.03	0.25	36.9	0.12

The deposit, which was worked for about eight years by Mr. Tuitton, of Agassiz, was acquired in April, 1945, by Hiram Cutler and son and operated under the name of Agassiz Lime Quarry.

Development and Operation.—The deposit has been worked from the south-western end by a quarry which by July, 1945, was about 75 feet long. The face was then about 50 feet high and 50 feet across. The limestone is hauled by a narrow-gauge railway a distance of about 200 feet to the crushing plant, which consists of a jaw-crusher and grinding mill powered by a 15-horse-power electric motor. The products of this plant consist of ground limestone for soil conditioner, coarse, medium, and fine chicken grit, and turkey grit. The capacity of the plant, which in July, 1945, was about 1 ton per hour of these products, was limited by the size of the electric motor, and power for a large motor could not be obtained at that time.

SAN JUAN ISLANDS.

ROCHE HARBOR.

Location and Accessibility.—The Roche Harbor limestone-deposits are situated near the north end of San Juan Island on the peninsula south-east of Roche Harbor. Most of the deposits lie near the north-east corner of Section 23, Township 36 north, Range 4 west. All are readily accessible to an excellent harbour.

Geology.—The limestone-deposits consist of two or more beds of high-grade limestone, averaging about 50 feet in thickness, interbedded with graphitic cherts of the Devono-Carboniferous Orcas group. According to McLellan " the large accumulation of limestone at this locality is not due to the thickness of individual strata. As a result of the intensity of folding in this area, the folds have been locally overturned, and, as a consequence, each limestone layer is repeated at least three times in the quarries."

McLellan adds that " the only igneous material which actually cuts the limestone-deposits is some greatly altered sill-like andesitic material."

" The limestones, which are typically coarse to medium-grained and bluish-gray in colour, are completely recrystallized. Their purity and uniformity of composition throughout the deposit are remarkable, and it is easily practical for the company to guarantee a content of calcium carbonate in their product exceeding 98 per cent."

Development and Operation.—The deposits have been operated since 1882 by the Roche Harbor Lime & Cement Company. Thirteen more or less independent openings have been made on the exposures of limestone. Much of the limestone is being obtained from the floors of the old quarries. The operation is equipped with one 3/8-yard shovel and one 3/4-yard shovel. The limestone is hauled by truck to the lime plant which consists of thirteen vertical-stack kilns situated on the south-east shore of Roche Harbor.

The annual capacity of the plant is listed at 150,000 tons of crushed limestone, 45,000 tons of burned lime, and 12,000 tons of hydrated lime.

References.

Glover, S. L. (1936): Nonmetallic mineral sources of Washington—*Wash. Div. Geol.*, Bull. 33, p. 56.

Hodge, E. T. (1938): Market for Columbia River hydroelectric power using northwest minerals, Sec. III.—Northwest limestones—Vol. 1—*War Dept., Corps of Eng., North Pacific Div.*

McLellan, R. D. (1927): The geology of the San Juan Islands—*Univ. Wash.*, Publ. in Geol., Vol. 2, pp. 164, 165.

Shedd, S. (1913): Cement materials and industry in the State of Washington—*Wash. Geol. Surv.*, Bull. 4, p. 203.

COWELL LIMESTONE-DEPOSIT.

Location and Accessibility.—The Cowell limestone-deposit is situated on the south-western shore of San Juan Island in the North-east Quarter of Section 23 (and North-west Quarter of Section 24), Township 35 north, Range 4 west. Limestone is hauled by truck to scows at Smallpox Bay, an anchorage of limited size but affording shelter from all but westerly winds, 1½ miles north of the property.

Geology.—The limestone in this area occurs in a series of bedded rocks, including pillow lavas, bedded tuffs, breccias, and cherts, together with greenstone flows or sills. The limestone has yielded the fossil *Yabeina*, of Upper Permian age.

The western part of the deposit consists of a single easterly-trending limestone-band about 200 feet in thickness. At the shore this band dips southward at about 60 degrees. A few hundred feet inland the limestone has apparently been repeated three times by close folding and in this part the width of the limestone-outcrop approaches 600 feet. In the eastern part of the area, about 1,000 feet from the shore, two parallel steeply dipping south-easterly-trending belts of limestone are exposed. The structural relationship of these two belts to one another and to the westernmost band, exposed at the shore, is not known.

The limestone is dark grey to white in colour and moderately fine-grained. Discontinuous dolomitic beds and beds containing flint nodules are common and render a considerable part of the deposit unsuitable for production of commercial limestone.

Development and Operation.—Limestone has been obtained on this property from about ten more or less independent openings. The first workings, started about 1895, were situated a few hundred feet from the shore, where several lime-kilns, now abandoned, were erected. The present operation is being carried on, under a lease, by the Olympic Portland Cement Company, of Bellingham. This work has been confined to the eastern part of the property where limestone is being recovered from a series of small drift-free knolls and shipped chiefly as rock for pulp-mills. Lump rock is shovelled into trucks by means of a Bucyrus ⅜-yard shovel and hauled to a dock at Smallpox Bay where it is loaded onto scows ready for shipment. Spalls have been stock-piled and are being sold for cement manufacture. The company also operates a Williams No. 20 Slugger Mill powered by an 80-horse-power tractor engine for producing ground limestone.

Reference.

McLellan, R. D. (1927): The geology of the San Juan Islands—*Univ. Wash.*, Publ. in Geol., Vol. 2, p. 166.

WEST SOUND DEPOSIT.

Location and Accessibility.—The West Sound deposit is situated on Orcas Island on the east shore of West Sound ½ mile south-east of the settlement of the same name. It lies in the North-east Quarter of Section 9, Township 36 north, Range 2 west, only a few hundred feet from a wharf.

Geology.—The West Sound deposit consists of a bed of limestone 40 to 50 feet thick striking northerly and dipping about 45 degrees westward. It has been traced northerly across gently rising ground for about 1,000 feet from its outcrop on the shore. It is underlain by ribbon chert and serpentinous greenstone, overlain by a greenstone flow or sill. This limestone-bed has apparently been repeated by faulting and is exposed in a second place a few feet east of the first at its south end.

The limestone is white, recrystallized, and apparently of good grade.

A few crosscutting bodies of greenstone, possibly dykes, occur in the limestone.

Overburden varies from zero to over 12 feet in thickness.

Development and Operation.—The deposit has been worked since 1936 by the Roche Harbor Lime & Cement Company. The rock is now being obtained from a quarry which was started near the shore and has been worked northward for about 400 feet. The present face is between 30 and 40 feet high and more than 60 feet wide. Part of the limestone to the north of this face has been quarried from an old opening. The eastern belt of limestone has been exposed in a branch of the main quarry but is largely undeveloped.

The limestone is shovelled into trucks by means of a ½-yard shovel and hauled to the dock and scow. The rock is being sold to pulp-mills.

Reference.

McLellan, R. D. (1927): The geology of the San Juan Islands—*Univ. Wash.*, Publ. in Geol., Vol. 2, p. 168.

RED CROSS LEDGE.

Location and Accessibility.—The Red Cross ledge is situated near the north-west shore of Orcas Island about 3 miles south-west of the settlement of East Sound. It lies in the South-east Quarter of Section 20, Township 37 north, Range 2 west. The nearest harbours are at East Sound, almost 3 miles away, and West Sound, almost 5 miles away.

Geology.—The Red Cross ledge is about 100 feet thick, strikes westerly and dips southward at about 60 degrees. It is overlain and underlain by cherty argillites of the Devono-Carboniferous Orcas group. At its west end the ledge is apparently terminated by a north-westerly-striking fault, and at its east end, about 350 feet away, it disappears beneath a heavy cover of overburden.

The rock is moderately fine-grained and light grey in colour. Nodules and veinlets of flint and beds and veinlets of dolomite are common. Obscure fossils are visible in some places.

The ledge outcrops on a knoll up to 80 feet in height and is relatively free from overburden.

Development.—The deposit has been extensively quarried by the Roche Harbor Lime & Cement Company, but in December, 1945, the property was dormant.

MCGRAW-KITTINGER LEDGE.

Location and Accessibility.—The McGraw-Kittinger ledge is situated on the western part of Orcas Island 1½ miles west of the settlement of Dolphin. It outcrops on a bluff on the north slope of Mount Woolard at an elevation of 500 feet. It lies in the North-west Quarter of Section 2, Township 36 north, Range 2 west. At Dolphin, on East Sound, is the nearest point for loading scows.

Geology.—The McGraw-Kittinger ledge is thought to strike north-easterly and to dip at a high angle. Its thickness may exceed 200 feet. It occurs in chert of the Orcas group.

The limestone is of a light grey colour and moderately fine-grained. Magnesian and siliceous impurities are evidently widespread. The rock is reported to contain the Carboniferous coral *Lithostrotion.*

Development.—The ledge has been worked by a quarry estimated to be about 200 feet long, 200 feet wide, and averaging about 40 feet deep.

The deposit, worked in recent years by the Westerman Lime & Rock Quarry, was idle in December, 1945.

Reference.

McLellan, R. D. (1927): The geology of the San Juan Islands—*Univ. Wash.*, Publ. in Geol., Vol. 2, p. 167.

ORCAS KNOB QUARRIES.

Location and Accessibility.—The Orcas Knob quarries are situated on the north-west shore of Orcas Island from a quarter to a half mile west of the summit of Orcas Knob. They lie in the southern part of Section 30 and the northern part of Section 31, Township 37 north, Range 2 west. The products of these quarries were formerly shipped from an open bay a few hundred yards from the quarries. No sheltered harbour is available closer than West Sound, more than a mile to the south-east.

Geology.—The limestone, which in places exceeds 50 feet in thickness, strikes north-easterly and dips at a moderate angle into the precipitous hillside. The rock is dark grey in colour and apparently of good grade. Locally it contains fossil brachiopods, identified by Schuchert as *Atrypa reticularis* Linnæus, a Devonian variety.

Development.—The attitude of the bedding and the precipitous topography prohibited the quarrying of the limestone after the face had been advanced from a few feet to a maximum of about 100 feet from the base of the outcrop. At one time the limestone was burned at the property by the Orcas Lime Company. All operations were evidently abandoned many years ago.

Reference.

McLeilan, R. D. (1927): The geology of the San Juan Islands—*Univ. Wash.*, Publ. in Geol., Vol. 2, p. 168.

VANCOUVER ISLAND AND ADJACENT ISLANDS.

COBBLE HILL DEPOSIT.

Location and Accessibility.—Limestone occurs on the lower eastern slopes of Cobble Hill, in Lots 11 and 12, Range 5, Shawnigan Land District. The deposit lies from about ¼ to ½ mile from the Esquimalt & Nanaimo Railway at Cobble Hill Station and a similar distance from the Old Island Highway; it is about 31 miles by road or rail from Victoria and about 10 miles from Duncan.

Geology.—The limestone in this locality occurs in association with masses of black chert or cherty argillite a fraction of an inch to many feet in thickness. The total thickness of interbedded limestone and chert is not known, but apparently two or more limestone members, each more than 100 feet thick, are present. Parts of the limestone are of relatively high grade, parts are contaminated by nodules and irregular masses of chert, and a few parts are magnesian.

The structure of the deposit is evidently complex. At one point, about 2,000 feet south-east of Cobble Hill Station, bedding in the limestone dips gently north; at the quarry-site, 1,000 feet west of the station, it dips steeply south; elsewhere the irregular nature of the chert nodules and the absence of other signs of bedding has not permitted a determination of the attitude of stratification.

Dykes are rare.

Overburden is deep at the base of Cobble Hill, concealing the lower part of the limestone succession, but is relatively thin or absent on the slopes of the hill.

The limestone shows marked variations in texture. Parts are relatively fine-grained, but parts are composed of fairly coarse fragmentary organic remains and scattered pebbles in a finer-grained matrix. The latter contain numerous large crinoid stems and locally fragments of a ribbed brachiopod. Though not diagnostic, these fossils, together with the association of limestone and large bodies of chert, and with the absence of greenstone, suggest an Upper Palæozoic age for the deposit.

Development and Operation.—This deposit is being developed by Norman K. Bonner, of Cobble Hill. By the end of March, 1946, ¼ mile of road had been built to the mill-site, a mill had been erected and equipped with a Jeffrey No. 3 limepulver (jaw-crusher and hammer-mill with about 1/16-inch mesh-bars) powered by a Chevrolet automobile engine and a Ford Ferguson tractor with power take-off. The ground limestone is elevated to a bin to be distributed either in bulk or in paper sacks. A compressor had not been installed at that time. The quarry-face, about 100 feet up the hillside from the mill, was being cleared preparatory to development.

Two samples were taken across this proposed quarry-face, each composed of chips at 4-foot intervals along a line 48 feet long. The analyses of these samples are as follows:—

	Insol.	R_2O_3.	Fe_2O_3.	MnO.	MgO.	CaO.	P_2O_5.	S.	Ig. Loss.	H_2O.
South 48 feet	11.7	0.50	0.57	0.12	1.18	47.5	0.07	0.04	38.4	——
North 48 feet	10.7	0.32	0.43	0.11	6.65	41.8	0.05	0.06	39.8	——

RAYMOND DEPOSIT.

Location and Accessibility.—The Raymond limestone-deposit lies in Lots 9 and 10, Range 3, Shawnigan Land District, at the western base of Cobble Hill. It is situated on the Thaine Road, 1 mile from the Esquimalt & Nanaimo Railway at mile-post 29.2 north of Victoria, and is about 31 miles by road from Victoria and about 12 miles from Duncan.

Geology.—The limestone-deposit outcrops on a low knoll west of the Thaine Road and has an exposed width of about 120 feet. Both margins of the limestone are concealed by drift. Stratification in the limestone, as indicated by a few strings of cherty inclusions, strikes north-westerly and dips from 30 to 45 degrees north-eastward. The apparent stratigraphic thickness of the limestone therefore is at least 80 feet.

Overburden is light on the knoll but heavy adjacent to it.

The limestone is crystalline and white to grey. It possesses an unusual texture consisting of coarse grains, possibly shell fragments, embedded in a finer-grained ground-mass similar to that of the Cobble Hill deposit 1 mile to the east, with which it can be correlated.

Analyses.—Three samples, each composed of chips at 4-foot intervals across 40 feet, were taken along the face of the main quarry on the south-east side of the knoll. Analyses of these samples are as follows:—

	Insol.	R_2O_3.	Fe_2O_3.	MnO.	MgO.	CaO.	P_2O_5.	S.	Ig. Loss.	H_2O.
South-west 40 feet	4.1	0.25	0.32	0.03	0.41	52.9	0.06	0.03	41.9	0.04
Middle 40 feet	3.6	0.15	0.13	0.02	0.28	53.5	0.02	0.02	42.2	0.04
North-east 40 feet	2.2	0.24	0.11	0.02	0.37	54.1	0.04	0.02	43.0	0.04

Development and Operation.—Limestone was quarried and burned at this locality in 1886, the operation was continued for about 10 years by Raymond & Sons, and agricultural limestone is reported to have been quarried from this deposit for two seasons, about 1916 and 1918. The kiln remains but the quarries adjacent to it are overgrown. The main quarry, on the south-east side of the knoll, is about 120 feet long, and has a face up to 20 feet in height. A smaller quarry on the top of the knoll has a semicircular face up to 10 feet high.

Limestone from a second deposit, about 1,000 feet north of this knoll, is reported to have been quarried and ground for agricultural purposes for one season, about 1921.

Reference.

Clapp, C. H. (1917): Sooke and Duncan map-area—*Geol. Surv., Canada*, Mem. 96.

MOUNT BRENTON DEPOSIT.

Clapp[*] reports "a very small limestone lens 25 feet long and 10 feet wide on Mount Brenton, which is apparently intercalated with tuffaceous volcanics of the Sicker series. This is the only limestone, as far as known, which occurs with rocks of the Sicker series." The small size of this deposit would clearly preclude its commercial development.

SCHOONER COVE DEPOSITS.

Limestone is reported by Richardson[†] from Schooner Bay [Schooner Cove, *Ed.*], on the north-east shore of Vancouver Island, where it "occurs in beds from 3 to 5 feet thick, which are largely intermixed with masses of beautifully crystalline tremolite."

BALLENAS ISLANDS DEPOSITS.

Limestone was reported to occur on the Ballenas Islands, off the east shore of Vancouver Island and 15 miles north-west of Nanaimo, by Richardson.[‡] He notes 50 feet of "reddish very pure limestone in beds of from 2 to 18 inches thick, holding well-defined fossil stems of encrinites, corals, and brachiopods," on the south-eastern part of the larger (north) island. No such thickness of pure limestone could be found by the writer. The underlying rock, described by Richardson as "150 to 200 feet of grey limestone, in some parts interstratified with fine-grained black slate . . ." is predominantly argillaceous. No deposits of commercial size could be found on either island.

ANDERSON BAY DEPOSITS.

Location and Accessibility.—The Anderson Bay limestone-deposit is situated near the southern end of Texada Island from a quarter to five-eighths of a mile west of Anderson Bay (Fig. 5). What is presumably the same limestone outcrops on the west coast of Texada Island 1½ miles south-west of Anderson Bay. The limestone lies in Lots 26, 339, 345, and 340. Anderson Bay provides good shelter from most winds for tugs, barges, and small craft.

Geology.—The Anderson Bay limestone-deposit, about 200 feet thick, is interbedded with more or less schistose sediments, volcanics, and pyroclastics of the Anderson Bay formation (McConnell, 1914). It strikes northerly to north-easterly and dips westward at angles of from 30 to 60 degrees. It rests on a sheared greenstone breccia or squeezed volcanic conglomerate. At its northern end it is overlain by several hundred feet of mottled greenish and purplish flow-breccias and amygdaloids, above which rise steep bluffs of massive and ellipsoidal green volcanics, presumably those of the Texada formation. On the west coast of the island the limestone-outcrops hug the base of the bluffs, and the limestone is overlain directly by similar massive and ellipsoidal green volcanics. It is possible, therefore, that the latter rest unconformably on the breccias, amygdaloids, and limestones of the Anderson Bay formation. In the central part of the island the limestone is apparently missing. At its northern end the limestone is apparently truncated by a fault trending north-westerly along Anderson Bay and the valley draining into it. Limestone has been reported to occur near a small promontory on the east coast of the island between 1 and 2 miles north of Anderson Bay, and may be the faulted continuation of the limestone-deposit.

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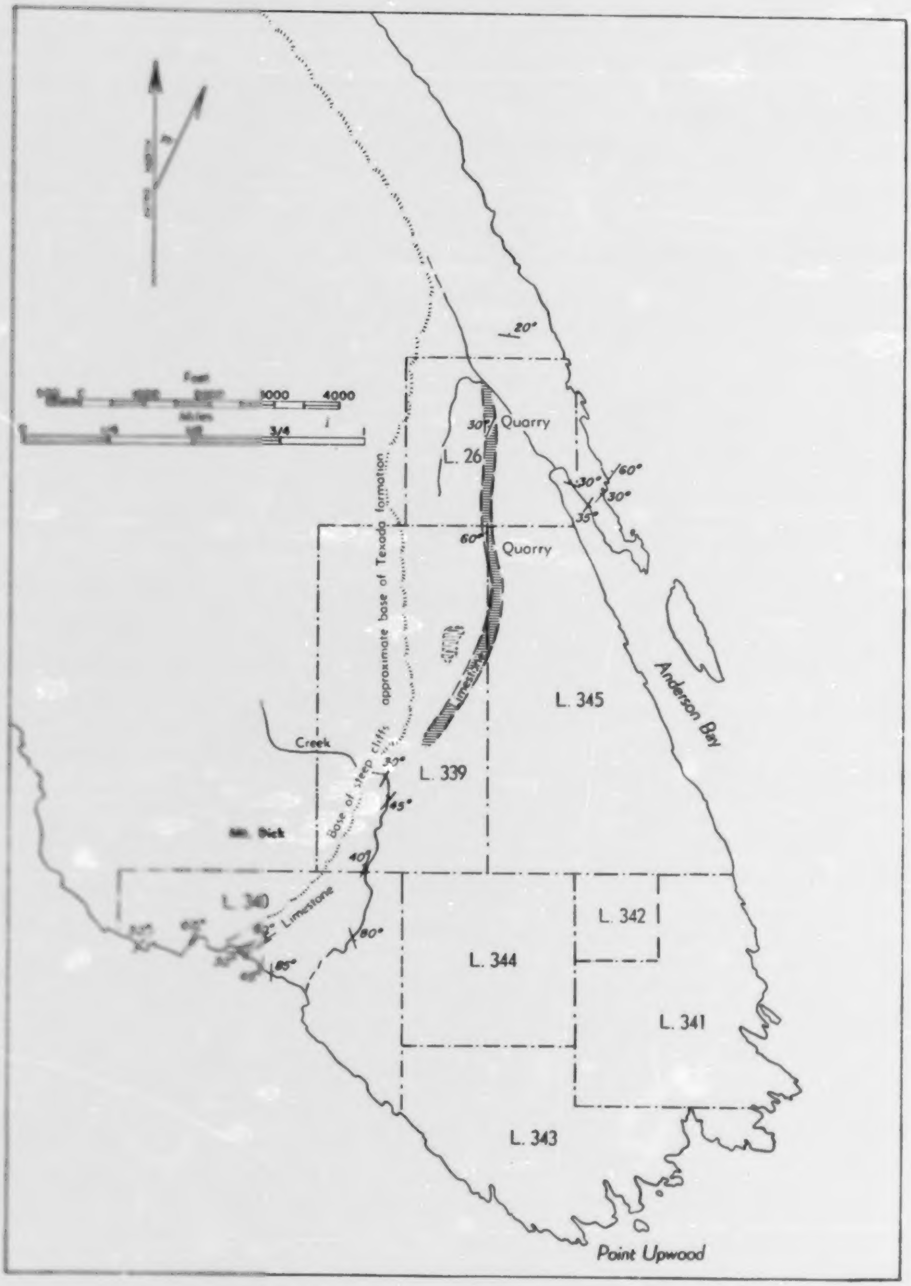
[*] Clapp, C. H. (1912): Southern Vancouver Island—*Geol. Surv., Canada*, Mem. 13, p. 67.

[†] Richardson, J. (1874): Report on geological exploration in British Columbia—*Geol. Surv., Canada*, Rept. of Progress for 1873-74, p. 97.

[‡] Richardson, J. (1874): Report on geological exploration in British Columbia—*Geol. Surv., Canada*, Rept. of Progress for 1873-74, p. 98.



20°
Feet
1000
4000
Miles
3/4
1
30°
Quarry
L. 26
30°
60°
30°
35°
60°
Quarry
approximate base of Texada formation
Limestone
L. 345
Anderson Bay
Creek
Base of steep cliffs
30°
L. 339
45°
Mt. Dick
40°
L. 340
Limestone
80°
85°
L. 342
L. 344
L. 341
L. 343
Point Upwood

Fig. 5. Anderson Bay area, Texada Island.

The lowermost 40 to 50 feet of the deposit consists of white to pink crinoidal limestone, grading upwards into a banded pink to red crinoidal limestone from 30 to 50 feet in thickness. In some places this red limestone contains lenses of jasper. It is overlain by red to green argillaceous and tuffaceous limestone. The upper half of the deposit is, in general, poorly exposed, but it evidently contains a considerable proportion of magnesian beds, together with white calcium limestone.

Imperfect fossils obtained from the limestone exposure on the west coast of the island have been identified as "*Spiriferina?*, a coral, crinoid stems, bryozoan" but are not diagnostic. In view of the apparent unconformable relationship of the Anderson Bay formation beneath the Upper Triassic Texada formation, the lithological similarity with Palæozoic rocks elsewhere in the Georgia Strait area, and the presence of the large fossil crinoid stems, the Anderson Bay formation is tentatively included in the Upper Palæozoic.

Analyses.—Analyses of the limestone are as follows:—

From Base.	Insol.	R_2O_3.	Fe_2O_3.	MnO.	MgO.	CaO.	P_2O_5.	S.	Ig. Loss.	H_2O.
134–175 feet	2.82	0.52	0.42	0.12	1.22	52.1	0.20	0.001	42.6	0.12
72– 87 feet	4.52	2.87	2.47	0.04	8.48	38.4	0.26	0.003	42.8	0.12
40– 70 feet	2.56	0.19	0.35	0.04	0.50	53.1	0.04	0.007	42.9	0.09
0– 40 feet	1.80	3.15	0.43	0.06	1.14	49.9	0.02	0.005	43.4	0.12

Development and Operation.—Two small quarries have been opened on this deposit for the recovery of ornamental stone. These are described by Parks, who also discusses in some detail the character of the stone. At that time Lot 339 was held by the Malaspina Marble Quarries Company, Limited, of Vancouver, and had been worked under royalty by the Continental Marble Company, also of Vancouver. Lot 26 was held by the Nootka Quarries, Limited, of Victoria, and Lot 340 by Wm. Astley, of Vancouver. So far as is known there has been no activity in this area since 1917, and all holdings of the above lots have lapsed.

References.

Dawson, G. M. (1887): Report on a geological examination of the northern part of Vancouver Island and adjacent coasts—*Geol. Surv., Canada*, Ann. Rept., New Ser., Vol. 2, pp. 1B–107B.

McConnell, R. G. (1914): Texada Island, B.C.—*Geol. Surv., Canada*, Mem. 58, pp. 14–17.

Parks, W. A. (1917): Report on the building and ornamental stones of Canada, Vol. V., Province of B.C.—*Dept. of Mines, Canada*, Rept. No. 452, p. 150.

HORNE LAKE DEPOSITS.

Main Limestone-deposit.

Location and Accessibility.—A thick deposit of limestone exposed on the north side of Horne Lake extends from the outlet of the lake westerly for a distance of 4 miles (*see* Fig. 6). Most of the limestone lies within Lots 250 and 251. The outlet of Horne Lake is 5 miles by road from Dunsmuir Station on the Esquimalt & Nanaimo Railway and 5½ miles from the Island Highway. Many of the roads leading to various parts of the deposit are owned by the Olympic Logging Company. Since logging operations in the vicinity of the lake were completed prior to 1945, these roads are not being maintained.

Geology.—A thickness of at least 1,200 feet of limestone is present in the central part of the area. The limestone is overlain with no apparent unconformity by massive greenstone and pillow lava similar to that of the Texada formation; it is directly underlain by banded greenstone or tuff. The rocks are folded into a broad northerly-plunging anticline complicated by several subordinate folds.

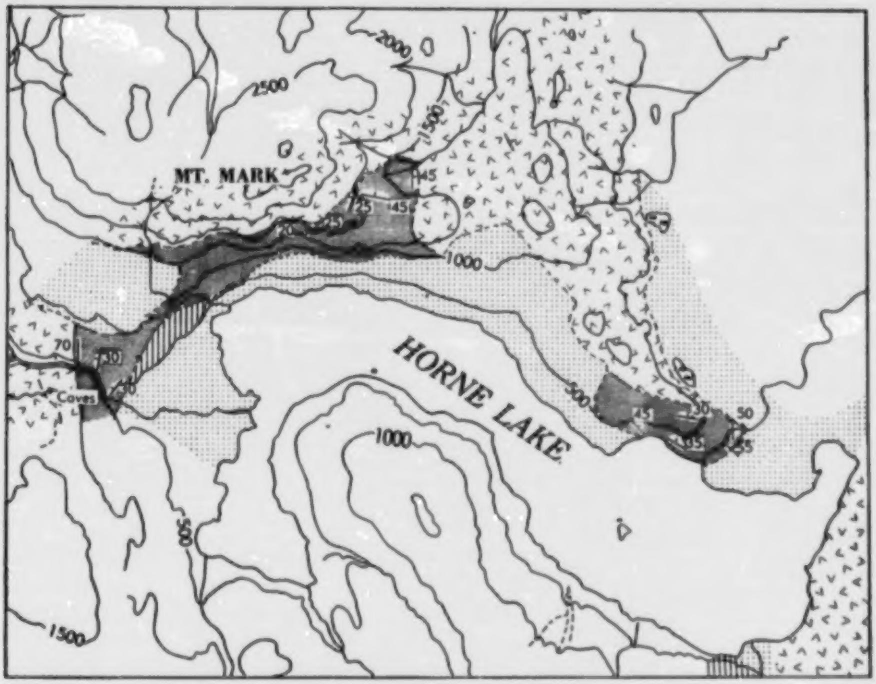


Fig. 6. Horne Lake area, Vancouver Island. Dot pattern—glacial drift, alluvium, etc.; pattern of v's—Texada volcanics; horizontal lines—Palæozoic limestones, chert, etc.; vertical lines—limestone tuffs, argillites, schists, etc.

The extension of the limestone southerly along the limbs of the major anticline has not been studied. At its eastern end the body of limestone passes south-easterly under the waters of Horne Lake. A limestone body has been reported in Cameron Draw, south of the eastern end of Horne Lake, but it does not extend either to the shores of Horne Lake on the north or to Cameron Lake on the south. The western limb of the main limestone body has been traced as far south as the crossing of Big Horn Creek which enters Horne Lake from the west.

The limestone is, in general, impure. Chert-beds averaging 1 to 4 inches thick are scattered at intervals of but a few feet throughout the upper part of the section. Parts of the limestone itself contain considerable proportions of insoluble matter; locally it is ferruginous, argillaceous, or tuffaceous. Gabbro sills are present in the upper part of the limestone on Mount Mark. The lower part of the section, exposed chiefly near the western part of Horne Lake, has not been studied in detail, but appears in general to be of better grade than the upper part.

Fragmentary fossils, chiefly large crinoid stems and cup corals, are scattered through the limestone and chert beds. Fossils collected by Richardson (1873, p. 54) were identified as:—

"1. Corals apparently of the genera *Zaphrentis* and *Diphiphyllum*.

"2. Large crinoid columns.

"3. *Fenestella* or *Polymorpha*.

"4. A large *Productus* and also a large *Spirifer*.

"They are so obscurely preserved that they cannot be determined specifically. They appear to be either Permian or Carboniferous, most probably the latter."

Development and Operation.—No attempt has been made to quarry or mine this deposit of limestone. The impurities in the rock render it suitable only for agricultural stone or cement rock. The distance from good transportation facilities and from markets is detrimental for any proposed development for agricultural stone. Quarry-sites could be located near the eastern end of the deposit on and to the north of the shores of Horne Lake.

Other Horne Lake Deposits.

Richardson (1873, p. 55) describes a series of slates, limestones, etc., in the area south-west of Horne Lake. None of these were examined by the writer. They are too remote from the east coast of Vancouver Island to be of value in any market there, but should demand arise for limestone at Port Alberni, 6 miles south-westerly, these deposits should be re-examined. It is possible, though by no means certain, that some of the deposits described by Richardson might be of sufficient size and quality to meet local needs.

Reference.

Richardson, J. (1873): Report on the coal fields of Vancouver and Queen Charlotte Islands—*Geol. Surv., Canada*, Rept. of Progress for 1872–73, pp. 32–65.

BUTTLE LAKE DEPOSITS.

Descriptions of the geology of the Buttle Lake limestone-deposits are given by Gunning (1930) and by Sargent (1940), but no information is available on the chemical composition. The deposits, though large, are much too remote at the present time to be of commercial interest.

References.

Gunning, H. C. (1930): Buttle Lake map-area—*Geol. Surv., Canada*, Sum. Rept. for 1930, Pt. A, pp. 55–78.

Sargent, H. (1941): Supplementary report on Bedwell River area, Vancouver Island, British Columbia—*B.C. Dept. of Mines*, Bull. 13, pp. 17–21, 73.

TRIASSIC LIMESTONE-DEPOSITS.

GENERAL.

The principal Triassic limestone-deposits are those of the Marble Bay formation,* well exposed and extensively quarried, on the northern part of Texada Island. The same formation is exposed in several other parts of the Georgia Strait area, but has not yet been worked in any of these localities. Smaller deposits, the so-called Sutton limestones, within the undifferentiated Vancouver series of Southern Vancouver Island have proved commercial. Limestone lenses are known in the Texada formation of the north-western part of the Georgia Strait area and calcareous sediments are reported from the Parsons Bay formation, but as far as is known none is of sufficient size and grade to have justified quarrying.

The Triassic limestone-deposits, unlike those of the Palæozoic, are rarely associated with or contain beds of chert. Argillaceous impurities are likewise rare except in the Marble Bay formation at Open Bay, Quadra Island, and in the Parsons Bay formation. The deposits are, however, generally associated with volcanic rocks and ill-defined or irregular bodies of greenstone—either flows, sills, or tuff beds—are present in many of the limestones. Fine-grained greenstone dykes and other intrusives are likewise common. Most of the deposits are composed of calcium or high-calcium limestone; locally, however, as in the upper part of the Marble Bay formation, magnesian

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* *See* page 38, Stratigraphy of the Georgia Strait area, Triassic rocks.

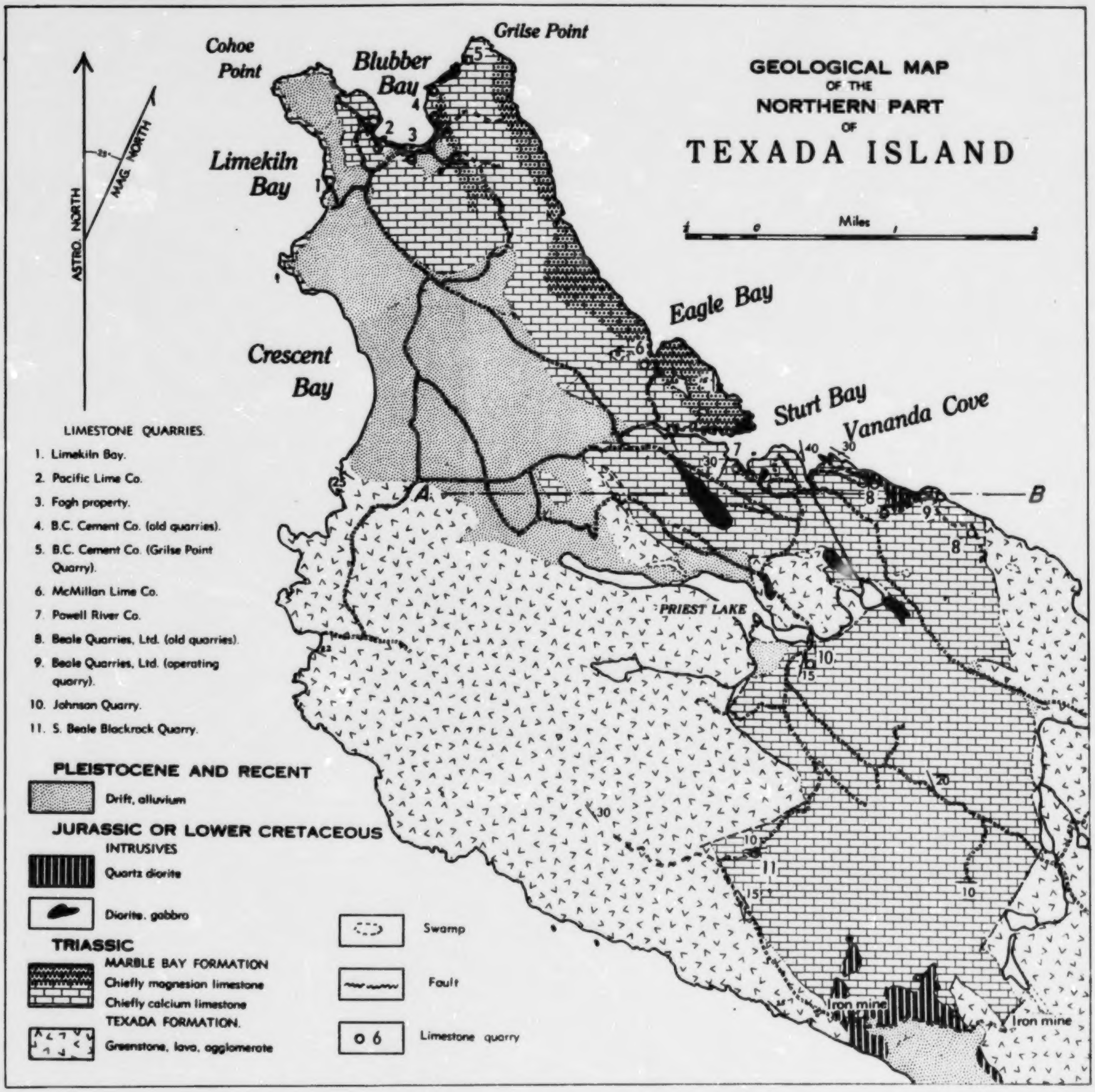
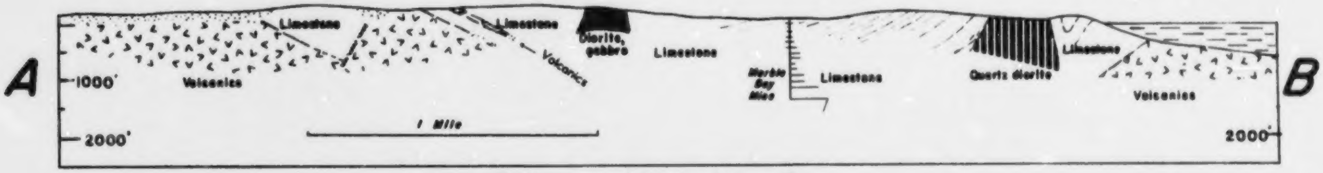

GEOLOGICAL MAP
OF THE
NORTHERN PART
OF
TEXADA ISLAND
Miles
ASTRO NORTH
MAG. NORTH
Cohoe Point
Blubber Bay
Grilse Point
Limekiln Bay
Crescent Bay
Eagle Bay
Sturt Bay
Vananda Cove
PRIEST LAKE
Iron mine
Iron mine
A
B
LIMESTONE QUARRIES.
1. Limekiln Bay.
2. Pacific Lime Co.
3. Fogh property.
4. B.C. Cement Co. (old quarries).
5. B.C. Cement Co. (Grilse Point Quarry).
6. McMillan Lime Co.
7. Powell River Co.
8. Beale Quarries, Ltd. (old quarries).
9. Beale Quarries, Ltd. (operating quarry).
10. Johnson Quarry.
11. S. Beale Blackrock Quarry.
PLEISTOCENE AND RECENT
Drift, alluvium
JURASSIC OR LOWER CRETACEOUS
INTRUSIVES
Quartz diorite
Diorite, gabbro
TRIASSIC
MARBLE BAY FORMATION
Chiefly magnesian limestone
Chiefly calcium limestone
TEXADA FORMATION.
Greenstone, lava, agglomerate
Swamp
Fault
Limestone quarry

Figure 7.—Northern part of Texada Island.


A
B
1000'
2000'
2000'
Limestone
Limestone
Diorite, gabbro
Limestone
Volcanics
Volcanics
Marble Bay Mine
Limestone
Quartz diorite
Limestone
Volcanics
1 Mile

Section on A-B of figure 7

Figure 8.

and dolomitic beds are present, but no dolomitic beds thick enough to provide a source of high-grade dolomite without sorting or beneficiation are known.

Rocks of Triassic age in the Georgia Strait area are confined almost entirely to British Columbia, and only one limestone occurrence of Triassic age has been reported in the north-western part of the State of Washington.

Except in Southern Vancouver Island the Triassic rocks have not, in general, been intensely folded. The thick accumulation of massive flows in the Texada formation presumably formed a rigid mass which for the most part yielded to stress by large-scale block-faulting and by tilting rather than by tight folding. In Southern Vancouver Island, however, the Triassic volcanics and the interbedded Sutton limestones dip steeply or are cut by a myriad of closely spaced faults. Close folding is also found in the eastern part of the limestone-belt of Quadra and Texada Islands in the upper part of the Marble Bay formation nearest the granitic intrusives of the Coast Mountains.

The Triassic deposits can be divided into (1) small deposits commanding only a local market and (2) larger deposits which lend themselves to cheaper large-scale development and which command correspondingly wider markets. In the former category may be included most of the Sutton deposits in the south-eastern part of Vancouver Island, and in the latter can be included the Marble Bay formation of Texada Island.

TABLE.

List of Triassic limestone-deposits operating, idle, or undeveloped:—

Locality.	Product.	Operator.	Status, December, 1945.
Northern Texada Island	Lime	Tacoma Steel Co.	Idle.
Northern Texada Island	Lime, hydrate, etc.	Pacific Lime Co.	Operating.
Northern Texada Island	Agricultural stone, etc.	Western Lime Products and Petrie Lime Co.	Idle.
Northern Texada Island	Cement rock	B.C. Cement Co.	Operating.
Northern Texada Island		McMillin Lime & Mining Co.	Undeveloped.
Northern Texada Island	Pulp stone, etc.	Powell River Co.	Operating.
Northern Texada Island	Pulp stone, etc.	Beale Quarries, Ltd.	Operating.
Northern Texada Island	Pulp stone, etc.	S. Beale and K. Johnson	Idle.
Northern Texada Island	Lime rock	S. Beale	Idle.
Northern Texada Island	White-rock	Various individuals	Operating.
Davies Bay, Texada Island			Undeveloped.
Open Bay, Quadra Island			Undeveloped.
Campbell River area			Undeveloped.
Southern Vancouver Island Sutton limestones—			
Bamberton	Cement rock	Associated Cement Co. and B.C. Cement Co.	Operating.
Tod Inlet	Cement rock	Vancouver Portland Cement Co. and B.C. Cement Co.	Abandoned.
Malahat	White-rock	F. Jefford	Idle.
Millstream	Lime, etc.	(?)	Abandoned.
Atkins Road	Sand-lime brick	Silica Brick & Lime Co.	Idle.
Parsons Bridge	Flux Lime	Tyee Copper Co. Victoria Lime Co.	Idle.
Rosebank	Lime	Raymond & Sons and Rosebank Lime Co.	Abandoned.

GEOLOGY AND LIMESTONE-DEPOSITS OF NORTHERN PART OF TEXADA ISLAND.

TEXADA FORMATION.

The Texada formation is made up of altered volcanic rocks, chiefly massive and amygdaloidal flows, pillow lavas, and possibly some agglomerate, together with greenstone masses of uncertain origin and lenses of limestone. Dykes are common, and although many dykes of similar character cut the overlying Marble Bay formation, some, at least, may be feeders for the extrusive members of the Texada formation.

The presence of limestone interbedded with the volcanics indicates that at least part of the formation was laid down under submarine conditions.

Rocks of the Texada formation outcrop on the west coast of Texada Island from Crescent Bay to the iron mines and inland as far as Priest and Emily Lakes. Flow contacts, pillows, and limestone-beds in this area dip moderately, averaging 20 degrees to the north-east. Similar rocks outcrop in the area east of a line from Paxton and Myrtle Lakes north to a point on the north-east shore of the island about ¼ mile east of Beale Quarries plant. Near this line the volcanics dip westward at angles of from 30 to 50 degrees.

Lenses, strings of lenses, inclusions, and beds of limestone are described by McConnell (1914, pp. 18, 20, 25, 68, 69, 71) as occurring within the Texada formation. Few of these are more than a few feet across and none are known to be of interest as a source of commercial limestone.

MARBLE BAY FORMATION.

Stratigraphy.

The Marble Bay formation is made up almost exclusively of calcareous rocks, ranging from high-calcium to dolomitic limestone. The formation can be subdivided on the basis of chemical composition into three members, each several hundred feet in thickness; the first and lowermost being composed almost exclusively of high-calcium limestone, the second made up predominantly of calcium limestone but including some magnesian and some high-calcium limestone, and the third and uppermost made up predominantly of magnesian limestone. Although it is doubtful that the contacts between these members, as mapped, lie at precisely the same stratigraphic horizon throughout the northern part of the island, the members themselves nevertheless represent definite stratigraphic units.

The base of the Marble Bay formation is well exposed on the steep shore cliffs on the north-eastern shore of Texada Island 1¼ miles east of Vananda. Here a layer of limestone 2 feet thick, striking north 10 degrees west and dipping 30 degrees westward, rests on a succession of amygdaloidal flows and pillow lavas having the same attitude. Above this layer of limestone there is a flow or sill 6 feet thick followed by the main limestone succession. Talus about 50 feet west of this contact and apparently derived from a horizon higher in the limestone succession includes some pillow lava, and although no flows occur in place at the shore-line an isolated block of greenstone is embedded in the limestone a few feet west of the talus.

The contact of the Marble Bay and Texada formations is also exposed on the west side of the island one-quarter to three-quarters of a mile north-west of the Prescott mines. In this locality the strike of the bedding in the limestone and volcanics is variable, but the dips, except at one point, are between 10 and 30 degrees northeastward.

The contact of the two formations was seen at one other point, about 500 feet north-east of the Commodore mine and close to the north-eastern boundary of Lot 513. Limestone rests, at this place, on an irregular chilled upper surface of a porphyritic greenstone body. No weathering is recognizable in the greenstone, nor is any basal conglomerate present. The limestone itself is unaltered and relatively pure. At one point a tongue or clastic dyke of limestone extends for about 1 foot downward into the greenstone.

The Marble Bay formation, therefore, appears to rest conformably on the Texada formation. There is no suggestion of an erosional interval between the two formations, and it would seem that the change from a period of submarine vulcanism to one of submarine deposition of limestone was abrupt. Only east of Vananda and north of Priest Lake (*see* Figs. 7, 8) is there any apparent interbedding of limestone and volcanics near the contact of the two formations.

The first member of the Marble Bay formation is best exposed on the precipitous shore cliffs between the Beale Quarries, Limited, wharf, 1 mile east of Vananda, and the top of the Texada formation, ¼ mile farther east. Pacific Lime Company's No. 1 quarry penetrated the upper 300 feet of the member but did not reach its base. Partially exposed sections of the member occur in the southern portion of the limestone-belt near the iron mines. Each of these sections is composed almost exclusively of high-calcium limestone (*see* tables of analyses, pages 73, 83). Several magnesian beds a few inches to a few feet thick occur in the upper part of the first member in the Nos. 1 and 2 quarries, Beale Quarries, Limited, but these make up a very small proportion of the total section exposed there.

The base of the second member is marked at Blubber Bay by an abrupt change from the underlying high-calcium beds to a zone of calcium limestone, locally siliceous and magnesian, up to 25 feet thick, followed by beds of calcium and high-calcium limestone containing scattered magnesian beds. The base of the member is not exposed on the shore cliffs east of Vananda where a quartz-diorite stock separates the outcrops of the first and second members.

A shell-bearing horizon occurs in the lower part of the second member on the iron mines road 400 feet north-east of Stanley Beale's black-rock quarry, and not more than 100 feet above the top of the first member. The shells have been identified by F. H. McLearn, of the Geological Survey of Canada, as:—

"*Lima?* sp.
gastropods
Pecten n. sp.?
Age: Triassic?"

A similar shell-bearing limestone, also in the lower part of the second member, and possibly the same horizon as the last, outcrops on the west coast of the island at the south end of Limekiln Bay. The fossils from this locality have been identified by McLearn as:—

" indeterminate gastropods
coral
indeterminate ammonite, *Clionites?*
Lima? sp.
Age: Probably Triassic."

Only fragmentary sections of the lowermost few hundred feet of the second member are found, the best being to the west of Blubber Bay between the Pacific Lime Company quarries and the Government wharf (*see* Fig. 10, in pocket). Elsewhere this part of the formation is either partly concealed by drift in inland areas or in its possible exposures south of Grilse Point, complicated by faulting and folding.

Higher parts of the section are, however, well exposed on the shore of Limekiln Bay. The section at the Limekiln Bay quarry bears a distinct similarity to that near the Government wharf at Blubber Bay and is hence assumed to be several hundred feet above the base of the second member. From this quarry to the top of the second member near Cohoe Point the section is continuously exposed. The stratigraphic thickness of beds between the quarry and the top of this member, neglecting possible repetition or elimination of beds by faulting, is about 1,250 feet. The thickness of the second member is, therefore, estimated to be between 1,500 and 2,000 feet.

Another section of the second member is found along the eastern part of the island from the Little Billie mine to the head of Sturt Bay. The structure here is, however, complicated by cross-folding adjacent to some gabbro-diorite stocks, and no continuous section has been measured. The Marble Bay mine, started in the middle or upper part of the second member, penetrated to a depth of 1,570 feet below sea-level through limestone of the second and possibly also of the first member. As the mine was flooded in 1944 the section here could not be examined.

It is clear from examination of the sections described above that the second member of the Marble Bay formation is made up predominantly of calcium limestone. The lower part of this member is made up, in general, of calcium limestone with thin, widely spaced beds of magnesian or dolomitic limestone, and with a few thick beds of high-calcium limestone. In the higher parts of the member magnesia-rich beds are thicker and more numerous, but calcium limestone nevertheless predominates and locally high-calcium beds may be present, though nowhere are they known to exceed 20 feet in thickness.

The second member grades upward in the section from Limekiln Bay to Cohoe Point into a part of the succession in which magnesian beds predominate. This latter part of the succession may, therefore, be designated the third member. Rocks of similar composition and likewise above the second member outcrop north of Sturt Bay in a belt extending northward along the eastern shore of the island as far as Grilse Point. A third and smaller area of similar magnesia-rich limestones, which may also be referred to the third member, occurs east and south-east of Blubber Bay in the western part of the B.C. Cement property (Lot 12) and the eastern part of the Fogh property (Lot 9).

The section of the third member south of Cohoe Point consists of more than 500 feet of magnesian limestone interbedded with some calcium limestone, and possibly some dolomitic limestone. The lower limit of the member, where it is in contact with the calcium-rich limestones of the second member is not clearly defined, and the uppermost part of the member is concealed beneath the waters of the Georgia Strait. Since elsewhere on the northern part of the island the third member is highly folded and possibly faulted, no other section can be satisfactorily measured.

A closely folded belt of calcium and high-calcium limestones extending from Grilse Point to the head of Sturt Bay and bounded on either side by rocks of the third member is believed to represent the second and first members of the Marble Bay formation repeated in a major anticlinal structure, but could conceivably represent horizons above the third member exposed in a sharp synclinal structure. A further description of these rocks is given on page 76.

Structure.

The principal geological structure on the northern part of Texada Island is a northerly- to northwesterly-plunging syncline. The Marble Bay formation is exposed in the central part of this syncline in a belt 8 miles long and up to 2 miles wide. North and north-west of Vananda the eastern limb of the fold is concealed beneath the waters of the Georgia Strait. On either side of the limestone-belt the volcanics of the Texada formation dip beneath the Marble Bay formation at angles of from 20 to 50 degrees, and the limestones in the immediate vicinity of the contact have similar attitudes.

Although the principal structure of the Marble Bay formation is simple, smaller structures within the formation show wide variations in complexity. In parts of the syncline, for example near Limekiln Bay and in the area between the iron mines and Emily Lake, the beds are warped into gentle folds whose limbs in few places dip more steeply than 30 degrees. In the south-western part of Blubber Bay the first member of the Marble Bay formation has been exposed at the crest of a broad dome or north-easterly-plunging anticline. The Limekiln Bay quarry lies on the western part of a shallow basin-shaped structure. On the other hand the structure in a belt extending from Grilse Point to Sturt Bay is exceedingly complex (*see* pages 76–79). Here close folds a few tens of feet across, many of them overturned, are common, and at least one major fold involving many hundreds of feet of strata and likewise overturned is present. The relationship between this belt of highly folded limestones and the gently folded strata west and south of Blubber Bay is, unfortunately, partly concealed. Nevertheless, a transition from gently folded beds on the west to more closely folded beds on the east is indicated. The reason for the localization of intense folding to the belt south of Grilse Point is not certain.

Faulting has complicated the geological structure of the northern part of Texada Island. Many normal faults, but only a few small reverse faults, have been recognized. In many cases the displacement of the normal faults is small, ranging from a few inches to a few feet, but in a few cases the faults are of much greater magnitude. Since, however, there are no recognizable horizons within either the Marble Bay or Texada formations, these major faults can be detected, in general, only where they cross and displace the Marble Bay-Texada contact. This contact normally trends northerly or north-westerly, parallel to the strike of individual beds, but in several places it follows a north-easterly or easterly course for as much as several hundred feet. Where such a north-easterly- or easterly-trending contact is exposed, in pits and mine-workings, as at the Commodore mine (Lot 513), the Sentinel mine (Lot 423), and an unnamed working in the Rose Mineral Claim (Lot 196), steeply dipping shear-zones with limestone hanging-wall and greenstone foot-walls are exposed. In the deep, narrow open-cut north-east of the Lake iron mine (South-west Quarter of Lot 3) the immediate contact is now concealed, but the steep dip and the presence of copper mineralization suggest that here too the Marble Bay and Texada formations are in faulted relationship. It seems probable too that at most of the places where the contact follows a north-easterly or easterly trend it marks the site of a normal fault.

INTRUSIVE ROCKS.

Diorite-gabbro Stocks.

Diorite-gabbro stocks, many less than 200 feet across, a few larger, and one almost 1,000 feet wide and 3,000 feet long, occur in the vicinity of Vananda and Blubber Bay, intruding the Marble Bay and Texada formations (McConnell, 1914, pp. 28–30). They vary markedly in texture and composition. The limestone in the vicinity of the stocks is severely crumpled. It is probable that this crumpling has been brought about by the intrusion of the stocks, but it is also possible that, during subsequent folding, crumpling has been concentrated in the relatively plastic limestone near its contact with the relatively rigid diorite-gabbro.

Quartz-diorite Stocks.

Two quartz-diorite stocks, each at least several thousand feet long, one-half a mile east of Vananda (Stevenson, 1944) and one in the vicinity of the iron mines, 4 miles south of Vananda (Swanson, 1924), cut the Marble Bay and Texada formations. In the vicinity of the Vananda stock the limestone is crumpled and recrystallized; in the vicinity of the iron mines' stock the limestone is distinctly recrystallized, but as no stratification is visible no information is available on possible folding.

Dykes.

Basic dykes are common in both the Texada and Marble Bay formations but have been studied in detail only in the latter formation. The majority of the dykes are not more than a few feet in thickness and may be conveniently described as " greenstone." The only original feature observed in these intrusives is, in some cases, porphyritic texture. Larger dykes reach 20 to 40 feet in thickness and some of these, for example the dyke between Pacific Lime Company's No. 1 and No. 2 quarries, are sufficiently coarse in texture to be described as diorite.

A line of outcrops of quartz porphyry, apparently a single belt of *en échelon* dykes, none more than 40 feet across, extends from Limekiln Bay east to the north-east shore of the island, a total distance of 4,300 feet.

In most cases the dykes have been more resistant to erosion than the adjacent limestone, and as they commonly project from a few inches to several feet above their surroundings they are generally conspicuous. Along the shores these dykes give rise to long, narrow, steep-sided reefs projecting out towards the deep water. On the other hand, some of the smaller and more closely fractured dykes, where subject to wave-action, are readily eroded and form the loci for small chasms. In the immediate vicinity of Beale Quarries, Vananda, the basic dykes have been severely crushed, eroded, and subsequently buried under a rubble fallen from the more resistant limestone-walls. In this area the dykes are apparent only along the shores and in excavations.

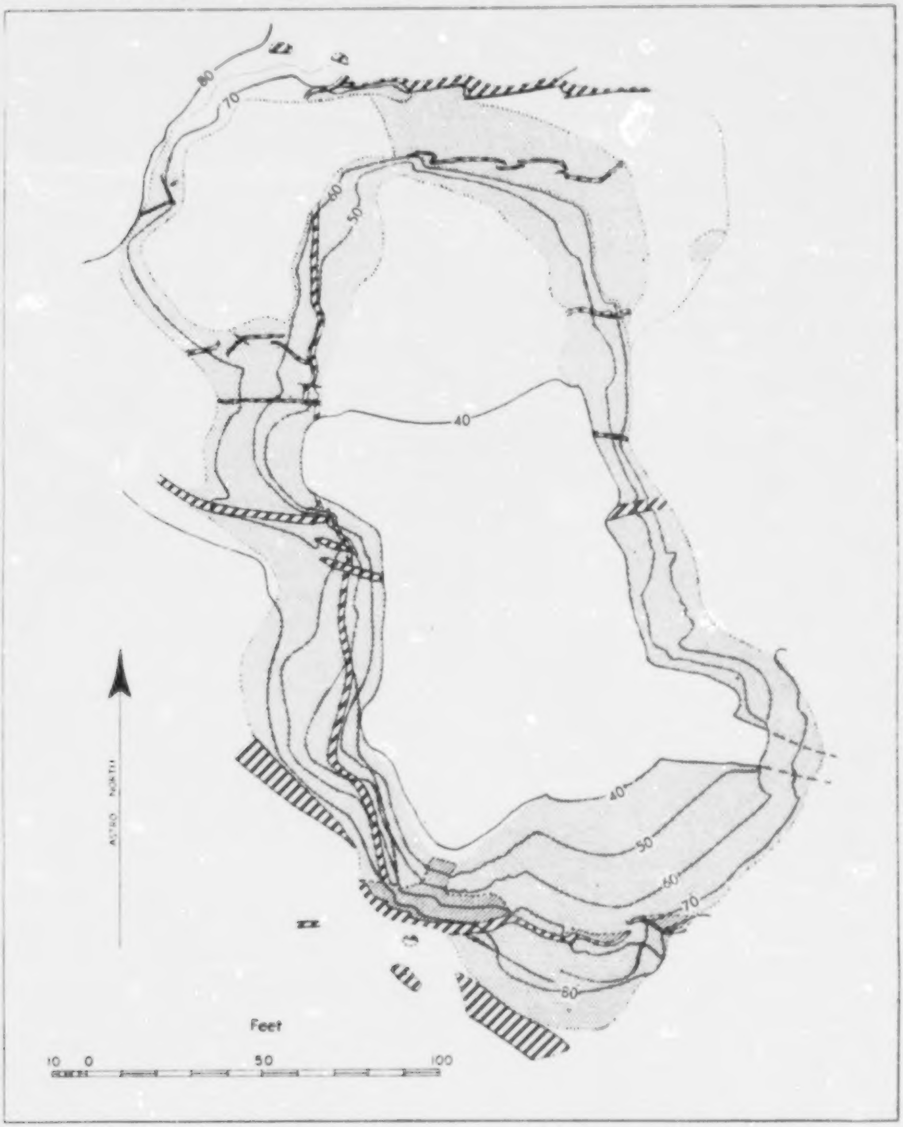


Fig. 9. No. 3 quarry, Pacific Lime Company. Dot pattern—limestone; heavy bars—dykes; fine-line pattern—walls of dyke exposed on quarry-face.

The frequency of dykes varies from place to place in the limestone-belt. In some parts, especially in the Blubber Bay area, the interval between dykes rarely exceeds 100 feet. A marked concentration of dykes was encountered in Pacific Lime Company's No. 3 quarry (*see* Fig. 9) and contributed to its abandonment. Elsewhere, on the other hand, dykes may be found only at intervals of several hundred feet.

Many of the dykes occupy the small normal faults cutting the limestone, and in a few places dykes have been crushed and sheared indicating that locally fault movements have continued after the intrusion of the dykes. In many cases, however, no faulting along the fracture occupied by the dyke can be detected. A few dykes, such as one at the eastern end of Pacific Lime Company's No. 2 quarry, occupy fractures which follow the axial plane of a minor bend in the strata.

In many places dykes narrow abruptly and terminate. One such dyke south-west of Pacific Lime Company's No. 3 quarry (*see* Fig. 9) pinches out from a thickness of 8 feet within a distance of 40 feet. Commonly the ends of such dykes are bowed or hooked, and in many cases a second dyke starts close to the point where one terminates. Thus a string of *en échelon* dykes is found, apparently occupying a system of tension fractures.

Dyke patterns are readily apparent in many places, and they bear, moreover, a distinct relationship to the attitude of the bedded rocks of the Marble Bay formation. Where the strata are only gently folded, as near Limekiln Bay and near the south-western part of Blubber Bay, the majority of the dykes trend south 70 to 80 degrees east and dip at high angles, generally to the south. A smaller number of dykes have an average strike of north 70 degrees east and south 45 degrees east respectively. A few dykes, notably the diorite dyke in Pacific Lime Company's quarries, alternate between two or three of the trends given above. On the other hand, at Cohoe Point, where the limestone-beds dip 50 to 70 degrees northward or north-westward, many of the greenstone dykes tend to follow the bedding-planes, and a few strike about south 50 degrees east and dip steeply either north-eastward or south-westward. In the vicinity of the British Columbia Cement Company's Grilse Point quarry several of the greenstone intrusives strike northerly, parallel to the foliation in the limestone, but elsewhere on the British Columbia Cement Company's property the intrusives generally cut obliquely across bedding or foliation, and several easterly-trending transverse dykes are known.

The *en échelon* arrangement of many dykes, especially those trending south 80 degrees east, in the Blubber Bay area suggests that they follow fractures produced by tension in a north-south direction. The presence of many dykes along the easterly-trending normal faults, as well as the scarcity of dykes having a northerly trend are in accord with this orientation of the stresses. Clearly, however, these stresses were directed by planes of weakness, either bedding-planes or planes of foliation already in existence within the folded limestones, and gave rise to a variety of fracture patterns which were followed by the dykes.

The age of the dykes is uncertain. Stevenson (1944, p. 166) reports that one group of greenstone dykes cuts only the limestone adjacent to the quartz-diorite stock east of Vananda, and a younger group also cuts the quartz diorite. Some easterly-trending dykes cut the diorite-gabbro stocks and some in the vicinity of the stocks are badly crushed (*see* page 82), possibly the crushing accompanied the intrusion of the stocks. The dykes as well as the stocks postdate the Upper Triassic Marble Bay formation, and they are not known to intrude the Upper Cretaceous sediments 2 miles south-east of the iron mines.

UPPER CRETACEOUS SEDIMENTS.

Upper Cretaceous shales, sandstones, and conglomerates are exposed near Gillies Bay and Mouat (Lower Gillies) Bay, 3 and 6 miles respectively south-east of the iron mines (McConnell, 1914, pp. 31–39). They rest unconformably on the Texada formation and are themselves slightly folded. These sediments are not known to be cut by any of the diorite-gabbro, greenstone, or quartz-diorite intrusives common in the area farther north.

QUATERNARY SEDIMENTS.

Glacial till is widespread in the northern part of the island but is nowhere known to be deep, and in many localities is absent. The till contains blocks of greenstone and, less commonly, of limestone, both presumably of local origin, as well as boulders of sandstone and conglomerate, similar to the Upper Cretaceous sediments of the eastern part of Vancouver Island, and of granitic rocks. Glacial striæ indicate that the ice moved south-easterly across the island.

Interglacial deposits and an older glacial till are present in a few localities, notably east of Crescent Bay and south-east of the iron mines (McConnell, 1914, pp. 39–41). Here they have accumulated to depths locally exceeding 150 to 250 feet and effectively prevent the examination and development of any underlying deposits of limestone. Beds of sand interstratified with silt in the Crescent Bay area, however, prove to be valuable aquifers and provide most of the water needed for industrial and domestic purposes in the Pacific Lime Company plant and adjacent townsite.

Late Glacial-raised beaches and post-Glacial alluvium are present on the island but are of limited extent.

References.

LeRoy, O. E. (1908): Preliminary report on a portion of the main coast of British Columbia and adjacent islands included in the New Westminster and Nanaimo districts—*Geol. Surv., Canada*, Rept. No. 996.

Carmichael, H. (1911): Limestone deposits of the coast—*Minister of Mines, B.C.*, Ann. Rept. for 1911, pp. 205, 206.

McConnell, R. G. (1914): Texada Island, B.C.—*Geol. Surv., Canada*, Mem. 58, pp. 12, 13, 17–21.

DESCRIPTION OF PROPERTIES.

Limekiln Bay Quarry.

Location and Accessibility.—The Limekiln Bay quarry is situated in Lot 23 on the shore of Limekiln Bay, and is accessible by road from Blubber Bay ½ mile to the north-east. At the time the quarry was operated loading facilities for boats were available on the shore of Limekiln Bay, but, as that bay is open, no adequate shelter could be provided for the shipping in the case of westerly gales. The bay is, moreover, shallow, and with the facilities then existing only shallow-draught boats and barges could land.

Geology.—The Limekiln Bay quarry lies in the lower part of the second or middle member of the Marble Bay formation. The base of this member is not exposed in the vicinity of Limekiln Bay, hence the exact stratigraphic position of the deposit with respect to that horizon is not known. The limestones, however, bear a marked resemblance to those exposed on the west shore of Blubber Bay near the Government wharf, and a few hundred feet stratigraphically above the base of the second member.

The limestone-deposit at Limekiln Bay is made up of alternating beds of calcium or high-calcium limestone, several feet in thickness, interbedded with magnesian beds generally a foot or less in thickness. The latter are, as a rule, themselves made up of fine but continuous laminæ of dolomite interbedded with calcium or magnesian limestone. One argillaceous bed, up to 3 inches thick, occurs in the lower part of the section. It overlies at the northern end of the quarry-face a conspicuous orange-weathering massive, rather than laminated, magnesian bed about 2 feet thick. An irregular lower surface of this bed suggests it originated by replacement, although at what stage of the history of the deposit is not evident. This bed does not appear 350 feet to the south-east at the opposite end of the quarry.

The beds have been warped into a broad saucer-shaped structure (*see* Fig. 1, page 12). Along the shore the beds dip northward or eastward at angles of from 10 to 20 degrees; inland at the quarry-face the beds dip northward at angles of not more than 15 degrees and become horizontal at the northern end of the quarry (*see* also page 12).

Several easterly-trending southward-dipping normal faults interrupt the continuity of the strata on both the quarry-face and the shore cliffs. The displacement on these faults varies from a fraction of an inch to about 10 feet (*see* Fig 1, also page 12).

No intrusives cut the limestone in the quarry, but a large dyke outcrops immediately north of the northern end of the face.

Overburden is missing or rarely more than a foot in thickness anywhere adjacent to the quarry, but it deepens appreciably a few tens of feet east of the quarry.

The limestone, like that of Blubber Bay, is, in general, black and fine-grained. The weathering which has taken place since the quarry was abandoned, about 1912, has been sufficient to differentiate the calcite and dolomite in the limestone. The latter stands up in relief as fine white laminæ, or less commonly as disseminated grains and short fine veinlets.

Analyses.—Channel samples were taken of individual beds throughout the complete stratigraphic section exposed at both the northern and southern ends of the quarry. In the following table analyses of the same beds at both the northern and southern ends of the quarry are listed together, the one from the southern end being in italics. The magnesia content of the beds is represented diagrammatically in Fig. 2, page 29.

Thickness.	Insol.	R_2O_3.	Fe_2O_3.	MnO.	MgO.	CaO.	P_2O_5.	S.	Ig. Loss.	H_2O at 105° C.
Top of section—										
3.0 feet*	0.40	0.58	0.14	0.012	1.73	52.87	0.013	0.03	43.92	0.01
6.0 feet	*0.20*	*0.14*	*0.05*	*0.005*	*2.17*	*53.68*	*0.011*	*0.02*	*43.47*	*0.02*
1.0 feet	0.60	0.63	0.35	0.019	7.88	46.20	0.021	0.09	44.18	0.05
0.0 feet (missing)	....	....	....	....	....	....	....	....	....	....
6.2 feet	0.50	1.10	0.07	0.008	2.06	54.79	0.012	0.03	41.83	0.04
7.5 feet	*0.80*	*0.15*	*0.03*	*0.005*	*1.09*	*54.69*	*0.015*	*0.04*	*43.48*	*Nil*
0.5 feet	0.30	1.15	0.13	0.009	7.24	46.91	0.020	0.02	43.83	0.02
0.5 feet	*0.30*	*0.20*	*0.08*	*0.009*	*5.92*	*49.34*	*0.013*	*0.04*	*43.90*	*0.03*
6.0 feet	0.30	0.60	0.14	0.009	5.25	49.64	0.014	0.04	43.56	0.05
8.7 feet	*0.60*	*0.07*	*0.12*	*0.008*	*7.85*	*47.42*	*0.014*	*0.06*	*43.92*	*Nil*
0.5 feet	0.30	0.49	0.43	0.019	13.00	41.06	0.016	0.13	45.00	0.02
0.0 feet (missing)	....	....	....	....	....	....	....	....	....	....
22.0 feet	0.20	0.23	0.06	0.009	0.58	55.69	0.008	0.03	42.98	*Nil*
22.2 feet	*0.60*	*0.15*	*0.04*	*0.005*	*0.77*	*55.29*	*0.011*	*0.04*	*43.10*	*0.03*
1.0 feet	0.70	1.18	0.30	0.026	7.50	47.72	0.018	0.07	43.07	0.04
0.0 feet	*1.80*	*1.65*	*0.34*	*0.016*	*7.42*	*46.51*	*0.014*	*0.07*	*43.25*	*Nil*
0.3 feet	32.40	37.16	6.44	0.021	9.59	2.02	†	†	12.52	0.01
0.2 feet	*40.92*	*37.59*	*5.01*	*0.041*	*4.09*	*3.94*	†	†	*9.81*	*0.60*
0.9 feet*	0.78	1.04	0.54	0.027	16.69	36.53	0.020	0.08	44.55	*Nil*
17.5 feet	*0.80*	*0.24*	*0.05*	*0.008*	*2.17*	*54.18*	*0.006*	*0.02*	*43.50*	*Nil*
Base of section in quarry.										

* Section at north end of quarry incomplete.
† Not determined.

Development and Operation.—Quarrying was commenced on this site in the late '90's of the last century, but was active at that time for only a short period. The Marble Bay Company, after encountering rock of an unsatisfactory grade for the production of lime in their Marble Bay quarry, acquired Lot 23 in 1902, erected a kiln, and recommenced quarrying. This operation, later extended with the construction of three additional kilns, continued under the management of the Marble Bay Company and of the Tacoma Steel Company until about 1912. There is no record of production since that time. Lot 23, together with Lots 5, 22, 36, 38, and certain Crown-granted mineral claims are still held by the Tacoma Steel Company.

The quarry-face is about 600 feet long, up to 35 feet high, and has been advanced a maximum of 100 to 150 feet from its initial location. Broken rock was apparently sorted by hand, and a large amount of waste remains stacked on the quarry-floor. Usable rock was trammed on a narrow-gauge railway from the face to the four kilns situated on the shore at the south end of the quarry. Burned lump-lime in barrels was apparently loaded into boats from a shed on the steep shore cliff near the north end of the quarry.

Reference.

McConnell, R. G. (1914): Texada Island, B.C.—*Geol. Surv., Canada,* Mem. 58, p. 97.

Pacific Lime Company, Limited.

Location and Accessibility.—The Pacific Lime Company's quarries are situated in the northern part of Lot 13 near the south-western shore of Blubber Bay. Good harbour facilities are available within a few hundred feet of the quarries.

Geology.—The deposits which have been worked by the Pacific Lime Company, Limited, lie within the upper part of the first member and the lower part of the second member of the Marble Bay formation. Quarry No. 1 appears to have been started on the outcrop of the top of the first member, and was subsequently worked to a depth of almost 300 feet below the original surface and 238 feet below sea-level before being abandoned in 1942. Quarry No. 2, adjacent to No. 1, lies within the upper part of the first member and the lowermost few tens of feet of the second member. Quarry No. 3 is entirely within the second member at an undetermined distance above its base.

The first member of the Marble Bay formation here, as at Beale Quarries and elsewhere, apparently is composed entirely of high-calcium limestone. The rock obtained from No. 1 quarry is reported to have been uniformly high-grade from top to bottom. The same strata exposed in No. 2 quarry are composed of high-calcium limestone, and analyses of drill-cores obtained by the company show that high-calcium rock persists here to a depth of at least 240 feet below the floor of No. 2 quarry. As might be expected in rock having such a limited range in composition, stratification is not readily apparent. A few gently dipping continuous fractures paralleling the bedding in the overlying second member may perhaps mark discontinuities between successive strata. No other evidences of stratification could, however, be found. In many places the rock is broken by sets of fairly uniformly spaced plane fractures which generally meet the stratification of the overlying beds at a high angle. The extreme regularity of this fracturing is further testimony of the marked uniformity in the characteristics of the limestone of this first member.

The base of the Marble Bay formation is exposed nowhere in the vicinity of Blubber Bay, hence the total thickness of high-calcium beds here is not known. It must, however, exceed 300 feet, the thickness exposed in No. 1 quarry, and may be comparable to that of the first member at Beale Quarries, Vananda, 5 miles to the south-east, where it approximates 500 feet.

In the second member of the Marble Bay formation, exposed in Nos. 2 and 3 quarries, the chemical composition of the limestone is neither as high grade nor as uniform as in the first member. In neither quarry, however, has weathering proceeded to a stage in which variations in mineralogical composition are evident as is the case at the Limekiln Bay quarry (*see* page 68). Stratification is made apparent only through the variations in physical characteristics of the rock. The gently dipping " bedding-fractures " are more conspicuous and more closely spaced than in the upper

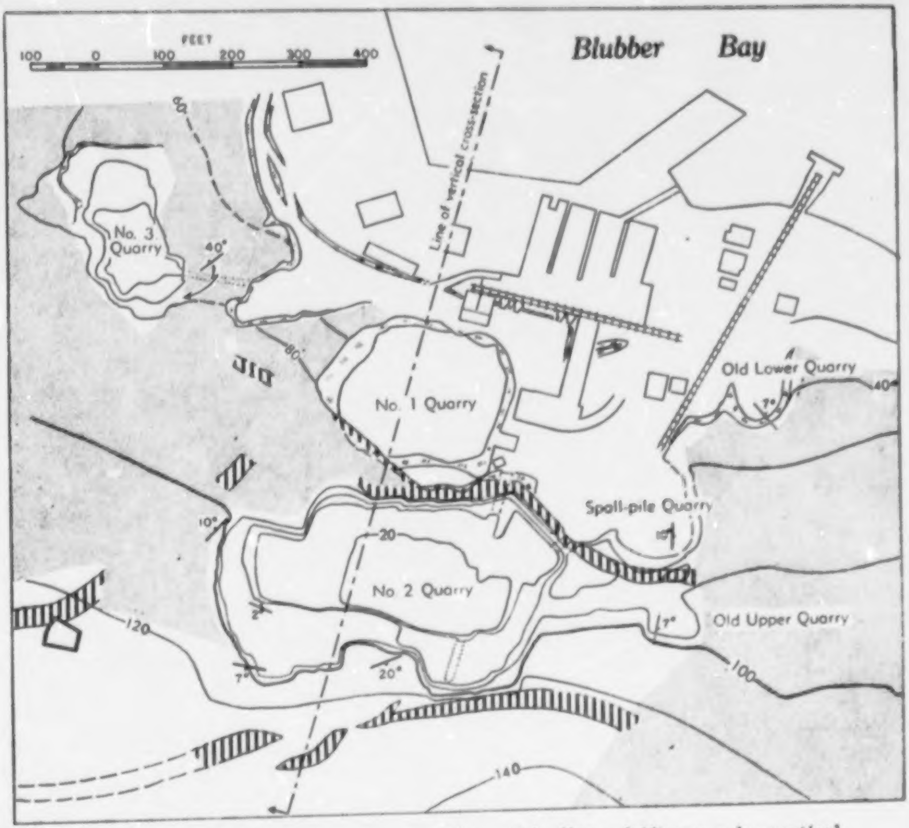

FEET
100
0
100
200
300
400
Blubber Bay
Line of vertical cross-section
60
No. 3 Quarry
40°
80
No. 1 Quarry
Old Lower Quarry
40
7°
Spall-pile Quarry
10°
10°
20
No. 2 Quarry
2°
7°
20°
7°
Old Upper Quarry
120
100
140

Fig. 11. Pacific Lime Company quarries. Stippling—drift-covered; vertical bars—diorite dykes. Contour interval—20 feet.

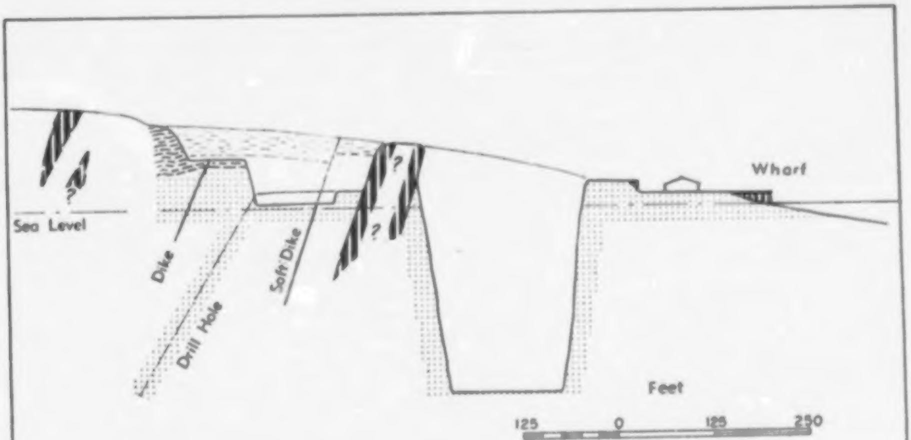

Sea Level
?
?
?
Dike
Drill Hole
Soft Dike
Wharf
Feet
125
0
125
250

Fig. 12. Cross-section of Pacific Lime Company quarries. Dot pattern—first member of Marble Bay formation; horizontal lines—second member of Marble Bay formation; vertical bars—dykes.

part of the first member. That these are parallel to stratification can be confirmed by chemical analyses. Some strata are harder and tougher than others; some possess a conchoidal fracture, others do not. Some strata, moreover, are closely and irregularly fractured; adjacent strata may be blocky-jointed. Nowhere, however, is there uniform fracturing, similar to that of the first member, extending across a thickness of more than a few feet of beds.

The stratification of the second member might easily be deciphered in this area were it not for marked changes in characters along bedding-planes. Variations of the chemical composition of the corresponding succession of beds in different places, as between opposite ends of the No. 2 quarry, are distinct. (*See* analyses, page 73). Whether these are brought about by progressive changes in most or all of the succession, or by the lenticular nature of a relatively minor thickness of impure beds, has not been determined. Changes in physical characteristics of the beds along strike are likewise noted. A bed susceptible to fracturing at one end of a quarry may be much less so at the other. The spacing of the bedding fractures varies to some extent, and some of these fractures appear or die out along the quarry-walls. It is not possible, therefore, to establish a single standard stratigraphic section, based either on chemical or physical characteristics, which is applicable over more than a single quarry or a part of a quarry. The contact between the high-grade and uniform rock of the first member and the less pure and variable rock of the second member is, however, distinct, and since, as far as can be determined, it lies at a single stratigraphic horizon throughout the quarries, it is one plane to which all sections are generally referred.

The major structure in the vicinity of the Pacific Lime Company, Limited, quarries is interpreted as a broad dome in the strata complicated by faulting. Only the north-eastern flank of this dome is well exposed in the quarries; the north-western and southern flanks are partly exposed, and the south-western flank not at all. Dips in the strata exposed in the quarry radiate, in general, from a point near the south-western corner of No. 2 quarry. A few local divergences from this radial pattern occur, one in the south-eastern corner of No. 2 quarry adjacent to a major dyke and others in No. 3 quarry.

Near the centre of the dome the dips rarely exceed 5 to 10 degrees, except in the disturbed zone near the major dyke, mentioned above, in No. 2 quarry. In No. 3 quarry, however, about 500 feet from the centre of the dome, the dips locally reach 40 degrees.

The top of the first member in the southern half of No. 2 quarry is followed closely by the floor of the upper bench, rising from an elevation of about 45 feet above sea-level at the eastern wall of the quarry to about 73 feet near the centre of the dome at the south-western corner of the quarry. Near the western end the continuity of this horizon is interrupted by an irregular network of at least four steeply dipping faults whose displacement varies from a few inches to possibly 10 feet. An easterly-trending southward-dipping normal fault crosses the northern part of No. 2 quarry and is marked by a crushed dyke. North of this fault the top of the first member is from 10 to 20 feet higher than at corresponding points immediately south of the fault.

Large diorite dykes and smaller greenstone dykes are common in the vicinity of the quarries. One of the diorite dykes separates Nos. 1 and 2 quarries, a second lies immediately south of No. 2 quarry. Smaller dykes are widespread. One concentration of dykes was met in No. 3 quarry (Fig. 9, page 66), but only one dyke is reported from No. 1 quarry and only two, with branches, occur in No. 2 quarry. With but one exception the dykes in the quarry area are steep dipping, and easterly trends predominate. Most of the dykes follow joint-planes but one or two follow fault-planes.

Overburden varies from zero to at least several feet in thickness. In many places the limestone is effectively concealed, whereas the dykes, being more resistant to erosion, project above the overburden.

The rock from the quarries is, in general, black and fine-grained. Impurities in the beds of the second member consist for the most part of dolomite and quartz, either disseminated as grains so fine that nearly all pass a 40-mesh screen, or locally as minute veinlets. The mineralogical character of the few impurities in the rock of the first member has not been recognized.

Vein-like and irregular masses of white limestone are found within typical black limestone in various parts of the quarries. The vein-like masses, which may be a fraction of an inch wide and several feet long, usually cut across the bedding. They occur in swarms, which in many cases are confined to a single stratum. Careful sampling of the white-rock shows that it is almost identical in chemical composition with the adjacent black-rock, apparently differing significantly only in the content of free carbon. The white-rock here has evidently been formed by the bleaching of black limestone adjacent to fine fractures by solutions or vapours which have migrated along them. No obvious fracture now exists along most of the white-rock veins. Many apparently irregular bodies of white-rock, notably adjacent to the dyke on the north wall of No. 2 quarry, are actually composed of a coalescing network of broad vein-like masses. The bleaching of black limestone is accompanied by certain physical changes.

Analyses.—Samples were collected by the writer from strata exposed in No. 2 quarry. All but two of the analyses quoted are of samples obtained from the south-eastern part of No. 2 quarry, but, to show the variations along strike of the bedding, two additional analyses of the same strata exposed at the western end of the quarry are also given. The first of these, 20.6 feet in thickness, is from beds corresponding to the 19.5-foot section from the south-eastern end of the quarry; the second, also 20.6 feet in thickness, is, however, from beds corresponding only to the upper 20 feet of the 27.3-foot section from the south-eastern corner.

	Insol.	R_2O_3.	Fe_2O_3.	MnO.	MgO.	CaO.	P_2O_5.	S.	Ig. Loss.	H_2O.
Quarry rim—										
17.5 feet	0.74	0.04	0.08	0.010	3.73	51.55	0.007	0.03	44.09	0.08
26.8 feet	0.64	0.03	0.09	0.020	2.62	52.59	0.010	0.04	43.96	0.07
19.5 feet	0.48	0.04	0.11	0.024	2.10	53.78	0.007	0.03	43.79	*Nil*
*20.6 feet**	*0.68*	*0.01*	*0.10*	*0.016*	*1.99*	*53.71*	*0.008*	*0.07*	*43.78*	*0.05*
27.3 feet	3.24	0.08	0.43	0.075	6.81	46.23	0.007	0.05	43.19	0.01
*20.6 feet**	*0.73*	*0.01*	*0.11*	*0.018*	*2.06*	*52.17*	*0.017*	*0.05*	*44.05*	*0.04*
Top of first member—										
19.8 feet	0.23	0.01	0.04	0.015	0.47	55.35	0.012	0.01	43.74	0.01
20.0 feet	0.17	Tr.	0.04	0.006	0.46	55.33	0.021	0.02	44.03	*Nil*
Quarry floor.										

* Alternative samples, *see* notes above.

Development and Operation.—At some time between 1890 and 1900 Lot 13, along with Lot 12 on the opposite shore of Blubber Bay, was held by Carter Cotton, who attempted, unsuccessfully, to start a lime-burning industry on the bay. Lot 13 was subsequently acquired by H. W. Treat, of the Van Anda Copper and Gold Company. Treat, in turn, sold the property to W. S. Planta, of the Blubber Bay lime syndicate, who began quarrying and burning limestone on Lot 13 and continued operations for a year and a half. This syndicate's holdings were then sold in 1910 to the original Pacific Lime Company, Limited, which operated quarries and kilns until 1916. At that date a new company, bearing the same name, took over the operations and has continued production almost continuously to the present day.

History.—Initial developments of the deposit prior to 1911 consisted of two small quarries, one at the eastern edge and the other at the south-eastern corner of the quarry area (Fig. 11). Between 1911 and 1928 No. 1 quarry, together with the "Spallpile quarry," covering in all an area up to 600 feet long and from 200 to 300 feet wide, were worked from the surface down to a level 20 feet above the sea. During this time an adit was driven through the dyke on the south wall of No. 1 quarry, and a gloryhole and pit developed in what is now No. 2 quarry. From 1928 to 1942 most of the production was obtained by excavating No. 1 quarry, about 250 feet in diameter, to a final depth of 238 feet below sea-level. The operation of this quarry was discontinued in 1942, and it has since been slowly filling with water. No. 3 quarry, 100 by 250 feet in plan, was worked to a comparatively shallow depth between 1936 and 1938. Development and production since 1942 has been confined to No. 2 quarry, which in the summer of 1945 had reached a length of 500 feet with an average width of 250 feet. The floor of the lowest bench in this quarry was then about 5 feet above sea-level.

No. 2 quarry is being worked westward in three benches, 20 to 50 feet in height. Rock is broken by a combination of down holes from the top of a bench and breastholes and lifters drilled from the floor below. Wagon drills are used almost exclusively. The uniformity of the rock, in the lower benches especially, permits economical breaking and minimizes secondary blasting. Limestone is shovelled by power-shovels into trucks and hauled to a grizzly at the lime plant from which it is distributed to the kilns.

The company operates stack kilns and a rotary kiln, also a lime processing and hydrating plant, producing all types of quicklime and hydrated lime for building, industrial, and chemical uses, and for agricultural purposes.

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Fogh Property.

Location and Accessibility.—Several small quarries and test-pits in the northern part of Lot 9, on the south side of Blubber Bay, are at distances of from a few hundred to 2,000 feet from an old wharf at the north-western corner of the property, and approximately 1 mile by road from the Government wharf on the west side of Blubber Bay.

Geology.—The western half of the property is underlain by limestone of intermediate grades, the continuation of the second member of the Marble Bay formation of the Pacific Lime Company property to the west (*see* page 70), and of the first or westernmost belt of the British Columbia Cement property to the north (*see* page 76). East of this is the belt of magnesian limestone extending south from the British Columbia Cement property, and east of this again limestone of intermediate grades, with some foliated, possibly high-calcium, limestone.

At the western edge of the property the strata are gently folded, but eastward the folding becomes more intense and complex. The structure of the eastern part of the property is similar to that of the British Columbia Cement property.

Dykes, generally having an easterly trend, are common, and several small diorite-gabbro stocks outcrop in the north-central part of the property adjacent to the Paris mine.

An area of drift about a quarter of a mile in diameter occurs in the northern part of the property adjacent to the south-eastern corner of Blubber Bay. Elsewhere overburden is relatively thin or missing.

The rocks of the western part of the property are fine-grained and black. The magnesian limestone in the central part of Lot 9 is fine- to medium-grained and cream or light brown in colour. The limestone in the eastern part is fine-grained to granular, generally grey, and massive or foliated.

Analyses.—The belt of magnesian limestone extending into the property from the north was sampled along an old logging-road north-east of the Paris mine and south-east and south of the abandoned white-rock quarry. Each sample was made up of chips taken at 10-foot intervals for a distance of 100 feet. Dyke-rock was excluded from the samples. Analyses are as follows:—

Distance from:	Insol.	R_2O_3.	Fe_2O_3.	MnO.	MgO.	CaO.	P_2O_5.	S.	Ig. Loss.	H_2O. 105° C.
East edge of belt—										
0–100 feet	1.14	0.55	0.86	0.138	14.32	37.86	0.014	0.14	45.33	0.06
100–200 feet	0.70	0.63	0.40	0.121	16.81	36.82	0.011	0.03	44.80	0.04
200–300 feet	0.40	0.78	0.24	0.067	6.59	48.22	0.015	0.03	43.89	0.05
West edge of belt—										
300–400 feet	0.30	0.28	0.19	0.058	2.06	53.75	0.011	0.02	43.40	0.05

No other samples were taken on this property.

Development and Operation.—Lot 9 was held at some time prior to 1908 by Harry Trim, chiefly for the base metal rights to the Paris mine. The property was subsequently acquired by Messrs. Fogh, Cox, and Johnson. Fogh interested Swedish capital in the possibilities of lime production from the property and had a concrete lime-kiln erected for this purpose. Apparently because of failure to locate lime of suitable quality the operation was not a success. In 1929 the Western Lime Products Company, Incorporated, of Seattle, was producing chicken grit and agricultural limestone on the property. In 1931 the property was held by the Petrie Lime Company and leased from this company by Coast Quarries, Limited, of Vancouver, who for several months quarried white-rock from a point north-east of the Paris mine. No production has been recorded since 1931. In 1944 the property was held by Mrs. K. M. Fogh, of Seattle.

The largest of the several quarries is in the north-eastern part of the property. This quarry, approximately 100 by 150 feet in plan, was worked by Coast Quarries, Limited, for white-rock. In the north-western part of the property there are two quarries up to 50 feet long and about 30 feet wide and small test-pits are numerous.

Reference.

McConnell, R. G. (1914): Texada Island, B.C.—*Geol. Surv., Canada*, Mem. 58, p. 66.

British Columbia Cement Company.

Location and Accessibility.—The British Columbia Cement Company quarries are situated on Lot 12, east of Blubber Bay. This property is about 1¼ miles by road from the Government wharf on the west side of Blubber Bay. The company wharf is situated on the east side of the bay, close to the crushing plant, and is sheltered from all but north-westerly winds.

Several quarries have been opened on this property, two adjacent to the crushing plant, a third on the shore of Blubber Bay ¼ mile north of the plant, and a fourth near Grilse Point ½ mile north-east of the plant.

Geology.—The limestone-beds of Lot 12, unlike those of the opposite shore of Blubber Bay, are squeezed into tight minor folds a few tens of feet across and are faulted. It would prove exceedingly difficult to decipher the general stratigraphy and structure on this property were it not for the systematic programme of sampling and analysing of limestones carried out by the company to delimit areas of high-grade rock. With the aid of the assay plan, however, it has been possible to recognize six more or less well-defined belts of limestone of different grades, each several hundred feet wide, crossing the property from north to south. From west to east these belts are: (1) limestone of intermediate grades, including both calcium and magnesian limestone, exposed along the shore of Blubber Bay, (2) magnesia-rich limestone which continues southward into Lot 9 (*see* analyses on page 75), (3) limestone of intermediate grades, (4) high-calcium and calcium limestone, (5) limestone of intermediate grades, and (6) magnesia-rich limestone, exposed on the east shore of the island.

The fourth belt, composed of high-grade rock, terminates southward, with an irregular contact, against rock of intermediate grades near the southern edge of the property. The third and fifth belts are thus linked to form a crude horseshoe-shaped area of limestone of intermediate grades. This horseshoe is flanked, in turn, by the areas of magnesia-rich limestone. The distribution of the rocks of the five eastern belts indicates, therefore, the presence of a major, plunging fold, in which are but three stratigraphic units: (1) a succession of high-calcium and calcium limestones, (2) limestones of intermediate grades, and (3) magnesia-rich limestones.

Diamond-drill cores have been obtained from several places in and adjacent to the surface exposures of high-grade limestone to determine whether the major fold is anticlinal, in which case the high-grade rock would be expected to underlie an area greater than its surface extent, or synclinal, in which case the high-grade rock would be of more limited extent at depth. Of six vertical holes, 100 to 160 feet deep, drilled near the southern contact of the belt of high-grade limestone, two remained in rock of intermediate grades throughout their length, two collared in rock of intermediate grades passed downward into high-grade rock, and two were drilled in high-grade rock throughout their length. The information obtained from these holes thus favours the anticlinal hypothesis. Three holes drilled along the western edge of this belt indicate that its contact with lower-grade rock dips steeply westward. A gentle westward dip of the stratification at one point on the surface along the contact suggests that the beds are here not overturned, and again the anticlinal hypothesis is favoured. Four holes drilled along the eastern edge of the belt indicate, however, that here, too, the contact dips steeply westward, but as drag-folds overturned to the east prevail along the eastern shore of the island, it is possible that this eastern contact of the high-grade limestone is likewise overturned. No faulting has been detected at either contact. The stratigraphic section appears, therefore, to be made up of high-grade limestone at the base, overlain by limestone of intermediate grades, overlain, in turn, by magnesia-rich limestone, all being exposed in a major southerly-plunging anticline. Because of the presence of minor folds and possibly of faults, it is not possible to compute the precise stratigraphic thickness of the units of this succession, but, judging from the widths of the belts, the thickness of each is probably several hundred feet.

The general similarity of the stratigraphic succession here to that more firmly established elsewhere on the island is marked. Moreover, the eastern belt of magnesia-rich limestone has been traced south-eastward to Sturt Bay where it clearly lies at a horizon above the second member of the Marble Bay formation, and can, therefore, be termed the third member. It may also be correlated with the magnesia-rich beds exposed at Cohoe Point. The limestones of intermediate grades exposed in the horseshoe-shaped area apparently underlie the third member, and may therefore be referred to the second member; the high-grade limestone at the core of the fold may similarly be referred to the first member. Thinning of the strata at the flanks of the fold may account for the reduction from 1,500- or 2,000-foot thickness of the second member indicated in the Limekiln Bay and Marble Bay sections to only several hundred feet here. Comparable thickening of the first member at the crest of the major fold might in this case be anticipated.

The western belt of magnesia-rich limestone, bounded on either side by limestones of intermediate grades, is believed to mark the site of a closely folded syncline. A geological section across the full width of the property might, therefore, show an incomplete W-shaped structure, the easternmost limb of which lies beneath the waters of Malaspina Strait.

The limestones are intruded by a diorite-gabbro stock in the north-western part of the property, and in its vicinity the structure is still further complicated. High-calcium limestone bounds the stock on the south-west and south-east, truncating the western belts of intermediate and magnesia-rich limestones described above. Faulting and possible cross-folding occur in this vicinity.

The diorite-gabbro stock, mentioned above, outcrops along the shore of Blubber Bay for a distance of 1,000 feet and extends inland for 200 to 300 feet. Several smaller diorite-gabbro intrusives outcrop in the south-eastern part of the property.

Dykes are common, especially in the vicinity of the diorite-gabbro stock outcropping on the shore of Blubber Bay. Dykes commonly trend either a few degrees south of east or a few degrees east of north, paralleling the foliation. Several broadly curving dykes occur in the western part of the property. Except in the vicinity of Grilse Point quarry, dykes are generally resistant to erosion and stand up as conspicuous ribs, extending out beyond the shores as reefs.

Overburden is shallow over most of the area except near the south-eastern corner of Blubber Bay.

In the south-western part of the property, where the limestone is less closely folded than elsewhere, it is fine-grained and generally black. Magnesia-rich limestone-beds, however, tend to be cream-coloured throughout. The high-grade limestone of the core of the major fold is generally granular, foliated, and grey in colour.

The foliation of this high-grade limestone is apparently related to the folding; it tends, in general, to be parallel to the axial planes of the minor folds, and is better developed on the flanks of the folds than on their crests. In the northern part of the property the foliation dips steeply to the east, in the southern part it dips, in general, steeply to the west. Where, as at the Grilse Point quarry, the foliation dips into, rather than out of, a quarry-face, it leads to difficulties in the clean and efficient breaking of the limestone in primary blasting.

White-rock is developed locally, and, although in many places it parallels foliation, in other places it crosscuts any foliation and is clearly related to fractures.

Analyses.—Samples, each made up of chips taken at 10-foot intervals across a width of 100 feet, were obtained in the central part of the property across the full width of the belt of high-grade limestone. Dyke-rock where encountered was omitted in sampling but some white to cream-coloured feldspathic material, of uncertain origin, is included, and leads to an increase in the amounts of insoluble matter and R_2O_3.

West to East.	Insol.	R_2O_3.	Fe_2O_3.	MnO.	MgO.	CaO.	P_2O_5.	S.	Ig. Loss.	H_2O.
0–100 feet	0.16	0.33	0.12	0.013	0.34	54.98	0.012	0.04	43.98	0.08
100–200 feet	5.62	0.87	0.35	0.025	0.90	51.27	0.059	0.07	41.41	0.12
200–300 feet	0.16	0.45	0.11	0.009	0.28	55.17	0.023	0.03	43.87	0.07
300–400 feet	8.64	2.13	0.33	0.019	0.89	48.80	0.052	0.02	38.99	0.12
400–500 feet	0.20	0.12	0.06	0.026	0.32	55.14	0.023	0.03	44.10	0.08
500–600 feet	0.60	0.24	0.14	0.026	1.84	52.75	0.018	0.03	44.23	0.07

Development and Operation.—At some time in the '90's of the last century a pot-kiln was erected on the east shore of Blubber Bay for Carter Cotton, then owner of Lots 12 and 13, but because of the inferior grade of limestone quarried near-by and of the limited market for lime the operation was abandoned. Lot 12 was later acquired by the British Columbia Cement Company, who in 1930 commenced quarrying limestone to augment the production from their Bamberton quarry for the Bamberton cement plant. The quarrying was begun in two openings close to the crushing plant and wharf, but it soon encountered, as did Cotton's operation, inferior grades of limestone. A narrow-gauge railway was then laid northward along the shore of Blubber Bay for a distance of 1,000 feet and a new quarry opened on the belt of high-grade limestone at the southern contact of the diorite-gabbro stock. Quarrying was continued here until most of the readily available high-grade limestone above the track grade was extracted. The railway was then extended for an additional 1,250 feet along the shore, past the diorite-gabbro stock, to the exposures of the main belt of high-grade limestone, where a new quarry, still in operation, was opened.

In July, 1945, the currently operating Grilse Point quarry had a face about 800 feet long from north to south and from 20 to 50 feet high, which had been worked inland for distances of from 50 to 200 feet from the shore. A series of northerly-trending dykes dipping eastward parallel to the foliation in the limestone had been encountered and were being left in the central part of the quarry-face, but operations were being continued at either end of the quarry where these dykes had been by-passed. In an effort to obtain the greatest possible height of quarry-face, the quarry-floor has been worked down to a level of only 15 feet above zero tide at the northern end of the quarry which is periodically inundated when an exceptionally high tide is accompanied by a strong westerly wind.

Breast-holes and lifters are drilled into the quarry-face by air-drills mounted on tripods and by a wagon drill. The larger of the blocks of limestone obtained by primary blasting are bulldozed. The rock is then shovelled by means of a 2-cubic-yard Marrion electric shovel, a 1¼-cubic-yard Bucyrus Erie Diesel shovel, or a ⅞-cubic-yard Marrion gas-electric shovel into 6-cubic-yard Koppel dump-cars.

These cars are hauled by a 20-ton Vulcan locomotive with a 130-horse-power engine, a 12-ton Plymouth locomotive with a 100-horse-power engine, or an 8-ton Plymouth locomotive with a 70-horse-power engine along the ½ mile of narrow-gauge track to the crushing plant. There the limestone is passed across a travelling-bar grizzly, which eliminates minus 4-inch rock. The undersize passes directly to a storage bin of 19,000 tons capacity. Oversize passes to a 36- by 48-inch Dominion Engineering Company jaw-crusher, driven by a 160-horse-power electric motor, which can break to minus 4 inches at a rate exceeding 200 tons per hour. The product is elevated to the storage bin. Scows are loaded from this bin by means of a 32-inch conveyer-belt, 325 feet long, which discharges at a rate of about 500 tons per hour when travelling at 400 feet per minute. A 7½K gyratory crusher, breaking to 3 inches and powered by a 60-horse-power electric motor, is installed at the plant and used as a stand-by in case the jaw-crusher is out of operation for repairs.

A central power-house containing two Diesel generators with an aggregate capacity of about 600 horse-power supplies power for the crushing plant and for the electric shovel and a 300-cubic-foot Holman compressor at the quarry.

The product of the quarry and plant, limestone, crushed at the present time to minus 4 inches, is all shipped in bulk by scow to Bamberton.

McMillin Lime & Mining Company.

Location and Accessibility.—The limestone-deposit held by the McMillin Lime & Mining Company is situated in the North Half of Lot 3, adjacent to Eagle Bay on the east coast of the island 1½ miles north-west of Vananda Cove. Eagle Bay itself is small, but large enough to accommodate a tug and scow. It affords, however, good protection from storms. A wharf has been constructed on the east side of the bay near its head. The bay is about 3 miles from Vananda by way of the Blubber Bay road and a branch road across the property.

Geology.—Three south-easterly-trending belts of limestone of different grades, each several hundred feet wide, cross the property. The belt on the south-west consists essentially of high-calcium limestone, the middle belt of mixed calcium and high-calcium limestone, and the belt on the north-east of magnesia-rich limestone. The latter is exposed along the east shore of the island from Grilse Point on the north to Sturt Bay, south-east of this property, and is included in the third member of the Marble Bay formation. The south-western and middle belts evidently correspond respectively to the fourth and fifth belts of limestone of the eastern part of the British Columbia Cement Company property 2½ miles to the north-west and, presumably, to the first and second members of the Marble Bay formation. The magnesia-rich limestone underlies about one-half of the area of the property and the high-calcium limestone about one-sixth.

The strata exposed in Eagle Bay and on adjacent shores has been warped into a series of minor open folds, usually a few tens of feet across, and in most cases plunging gently north-westward. Dips rarely exceed 40 degrees. A few minor faults have been observed.

Stratification is not apparent, however, inland, and only on the basis of the correlation of belts between this and the British Columbia Cement Company's property is the structure assumed to consist of a major anticline which exposes underlying high-calcium limestone at its core.

Greenstone dykes are present in the property but are by no means as common as in the Blubber Bay area.

Overburden is thin or missing over much of the property. Two large swamps, each several hundred feet wide and more than 1,000 feet long, occupy a part of the property, and overburden may be deep in linear depressions or strike-valleys cutting across the property.

Analyses.—A series of samples of limestone have been obtained from the property, each composed of chips at 20-foot intervals across a width of 200 feet measured at right angles to the trend of the belts. The sampled section starts at a point about 500 feet south 10 degrees west of the head of Eagle Bay, and extends south 40 degrees west to the end of the good exposures, a point about 600 feet south 80 degrees east of the south-west corner of the property. Dyke-rock was not included in the samples.

Distance from North-east End of Section.	Insol.	R_2O_3.	Fe_2O_3.	MnO.	MgO.	CaO.	P_2O_5.	S.	Ig. Loss.	H_2O.
Belt of mixed calcium and high-calcium limestone—										
0–200 feet	0.50	0.14	0.16	0.028	0.43	55.80	0.014	0.05	43.15	*Nil*
200–400 feet	0.40	0.14	0.12	0.016	1.30	53.98	0.015	0.03	43.76	0.04
400–600 feet	2.00	0.50	0.39	0.023	2.28	52.97	0.016	0.11	41.78	0.02
600–800 feet	1.00	0.38	0.30	0.065	5.91	49.14	0.020	0.05	43.48	0.03
Belt of high-calcium limestone—										
800–1,000 feet	0.50	0.16	0.12	0.023	0.90	54.59	0.022	0.08	43.75	0.04
1,000–1,200 feet	0.50	0.15	0.08	0.023	0.25	55.19	0.019	0.03	43.76	0.05
1,200–1,400 feet	0.30	0.09	0.07	0.028	0.36	55.19	0.035	0.03	43.72	0.02
1,400–1,600 feet	0.40	0.23	0.15	0.048	0.40	55.59	0.017	0.04	42.97	0.04
West end of sampled section—area of drift-cover, including scattered outcrops of limestone of intermediate grades.										

Development and Operation.—The deposit was acquired from W. S. Planta in 1944 by the McMillin Lime & Mining Company, headed by P. V. McMillin, of the Roche

Harbor Lime & Cement Company, Roche Harbor, Wash. During the winter of 1944–45 the company completed the examination of the property and constructed a wharf at Eagle Bay and a road leading to this point from the system of roads already existent on the island. No further development had been done to the end of 1946.

Marble Bay Quarries.

Location and Accessibility.—The Marble Bay quarries are situated in Lot 1, on the west shore of Marble Bay, the south arm of Sturt Bay. A wharf and good shelter for shipping are available adjacent to the quarries. The property is less than 1 mile by road from Vananda.

One of the original quarries is situated about 175 feet west of the old lime-kiln on the west side of Marble Bay. The main quarry extends from 250 to 600 feet south-east of this kiln, and still another quarry extends from 750 to 950 feet south-east of the kiln. The latter quarry lies at the head of Marble Bay.

Geology.—The quarry is situated in the upper part of the second member of the Marble Bay formation and is probably 2,000 feet or more above the base of the limestone succession. The more than 200 feet of strata exposed in the quarries are made up of calcium and magnesian limestone with some high-calcium limestone; calcium limestone is generally predominant.

The strata dip westward and north-westward at angles of from 15 to 40 degrees.

A small diorite-gabbro stock is exposed along the shore adjacent to the lime-kiln for about 250 feet and extends inland for an unknown distance. Two north-easterly-trending dykes are exposed in the main quarry.

Overburden is rarely more than a few feet deep.

The rock varies in colour from black to light grey and the magnesian varieties are either pale brown or, where serpentine and other magnesian silicates have been developed, greenish. Most of the rock is moderately fine-grained.

Analyses.—Samples have been made up of chips taken at 2-foot intervals across 20 feet of beds. Dyke-rock was excluded from the samples.

	Insol.	R_2O_3.	Fe_2O_3.	MnO.	MgO.	CaO.	P_2O_5.	S.	Ig. Loss.	H_2O.
Old quarry, west of lime-kiln—										
Top	0.72	0.27	0.26	0.081	2.87	54.08	0.009	0.04	42.03	0.03
Bottom	0.68	0.09	0.14	0.023	3.89	53.50	0.012	0.06	42.08	0.04
Main quarry, west end—										
Top	1.44	0.18	0.20	0.040	4.05	52.47	0.013	0.05	42.00	0.06
Bottom	2.60	1.42	0.62	0.098	5.71	48.74	0.013	0.06	41.19	0.07
Middle section—										
Top	0.52	0.25	0.23	0.035	1.70	53.78	0.015	0.08	43.22	0.03
Middle	0.30	0.11	0.22	0.026	2.72	54.49	0.015	0.07	42.36	0.05
Bottom	0.44	0.12	0.27	0.030	3.69	52.87	0.015	0.06	42.87	0.06
East end—										
Top	0.68	0.34	0.14	0.014	4.00	51.26	0.013	0.04	43.52	0.04
	2.28	0.81	0.35	0.028	11.90	43.10	0.017	0.09	41.63	0.91
	0.90	0.13	0.12	0.016	0.75	55.86	0.007	0.04	42.35	0.07
Bottom	0.99	0.19	0.10	0.025	1.11	54.81	0.010	0.04	42.53	0.06
South-east quarry—										
Top	2.40	1.94	0.62	0.023	5.35	48.84	0.033	0.20	41.10	0.07
Middle	2.10	1.50	0.58	0.032	17.05	37.03	0.024	0.15	42.03	0.02
Bottom	1.30	0.58	0.30	0.058	5.72	49.14	0.016	0.10	42.91	0.04

Development and Operation.—In 1898 or 1899 Wm. Christie and J. J. Palmer, of the Marble Bay Company, built the lime-kiln on the west shore of Marble Bay and operated quarries and the lime plant for several years. As the quality of the lime produced from this property was not high, the Marble Bay Company acquired Lot 23 on Limekiln Bay and transferred their operations to that area. During or after World

War I. the Marble Bay quarries were reopened by the Tacoma Steel Company who shipped limestone to Powell River for use in the pulp-mill. In 1922 the Powell River Company acquired Parcel A of Lot 1, a total of 8.53 acres which includes the main quarry and the smaller quarry at the head of Marble Bay, and operated them until 1933. At this time the Powell River Company was able to get a more satisfactory limestone from a quarry newly opened east of Vananda by F. J. Beale, and the Marble Bay quarries were abandoned. In December, 1945, however, the Marble Bay quarries were being reopened by the Powell River Company under the supervision of Stanley Beale, son of F. J. Beale.

The westernmost quarry, from which the remnants of a narrow-gauge railway lead to the old lime-kiln, is about 50 feet in diameter and the walls are up to 15 feet high. The main quarry was operated in several more or less distinct faces totalling about 700 feet in length, each from 50 to 75 feet high. The smaller quarry at the south-east was worked in a single face 200 feet long and about 80 feet high.

References.

Carmichael, H. (1899): *Minister of Mines, B.C.*, Ann. Rept. for 1899, p. 804.
McConnell, R. G. (1914): Texada Island, B.C.—*Geol. Surv., Canada*, Mem. 58, p. 96.

Beale Quarries, Limited.

Location and Accessibility.—The workings of Beale Quarries, Limited, are on and near the north-eastern shore of Texada Island, from half a mile to a mile east of Vananda, on Lots 7 and 499, and are accessible by road from Vananda. Barges may be loaded directly from a wharf on the unsheltered shore at the site of Nos. 1 and 2 quarries. Protection for shipping is found at Vananda Cove, 1 mile to the west, which is of limited size and exposed to northerly and north-westerly winds, and in Sturt Bay, 1¼ miles to the west, which is both larger and more sheltered.

Six quarries have been opened by the company, Nos. 1 and 2, adjacent to one another, on the exposed shore cliffs about 1 mile east of Vananda, and Nos. 3, 4, and 5 quarries about 1,800 feet south-west, 2,000 feet west, and 2,000 feet south-east, respectively, of Nos. 1 and 2 quarries. A white-rock quarry is situated 1,500 feet south of No. 5 quarry.

Geology.—The quarries are in the lower part of the Marble Bay formation. Quarry No. 5 lies approximately 400 feet stratigraphically above the base of the Marble Bay formation and in the upper part of the first member. Quarry No. 2 may include beds both above and below the horizon of quarry No. 5. Quarry No. 1 is in badly folded and faulted beds at or above the horizons of quarry No. 2. Quarries Nos. 3 and 4, both at about the same horizon, lie within the second member probably several hundred feet above its base. The first member of the Marble Bay formation is here made up almost entirely of high-calcium limestone. As would be expected with its limited range in composition, physical characteristics are likewise relatively uniform and stratification is not readily apparent.

Several magnesian beds a few inches to a few feet thick outcropping in the Nos. 1 and 2 quarries are in the upper part of the first member. They make up but a small fraction of the section, only four beds being recognized on the cliff and quarry faces across an exposed width of almost 1,000 feet.

Higher parts of the section in the second member, exposed in Nos. 3 and 4 quarries, are made up of alternating beds of calcium and magnesian limestone, the former generally predominating, cut by a network of calcite and dolomite veinlets. Stratification can as a rule be distinguished in these rocks.

In the eastern part of the limestone-belt, from No. 2 quarry to the base of the formation, the strata dip westward at an angle of about 40 degrees. In No. 2 quarry, however, the westward dip steepens, and in the western part of this quarry and in No.

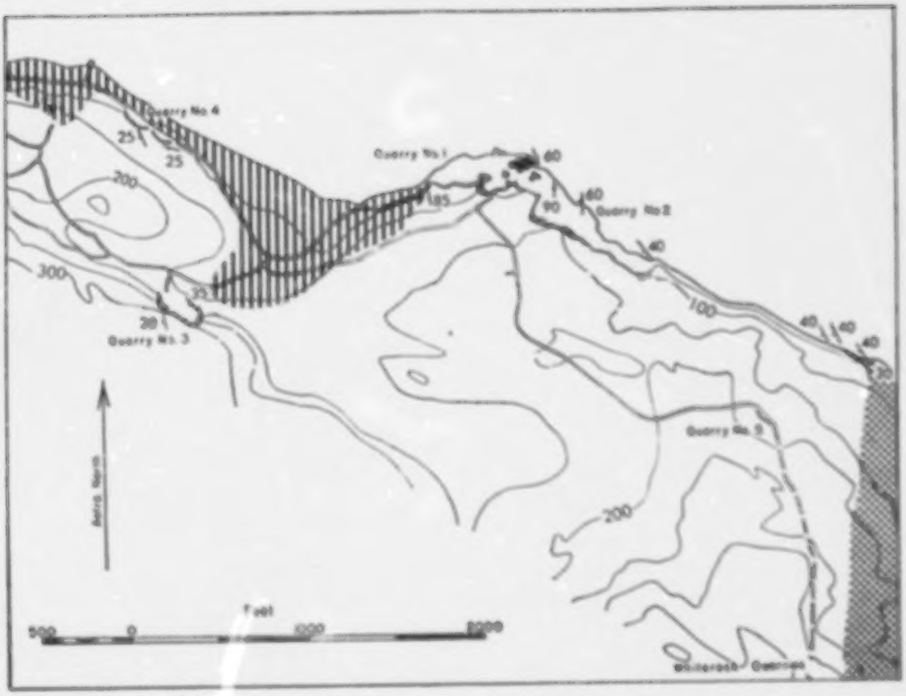

Fig. 13. Beale Quarries, Vananda. Vertical bars—quartz diorite; crossed ruling—Texada formation.

1 quarry the strata are apparently highly folded and faulted. This folding and faulting may be related to the intrusion of the quartz-diorite stock which adjoins No. 1 quarry on the west. South-west of the stock, as at quarries Nos. 3 and 4, moderate south-westerly dips of the strata prevail.

Faults are not apparent in the eastern part of the property but are abundant in quarries Nos. 1 and 2. The pattern of faulting here has not been deciphered. The quartz diorite is cut by faults trending approximately south 70 degrees east and dipping steeply southward near both the west end of No. 1 quarry and the Little Billie mine (Stevenson, 1944).

Greenstone dykes are present here, as elsewhere on the northern part of Texada Island, but they are not, in general, as common as in the Blubber Bay area. Nearly all the dykes cutting the volcanics underlying the limestone in this vicinity trend easterly, but no one trend prevails in those cutting the limestone itself. They vary in width from a few inches up to about 12 feet, and some irregular masses in quarry No. 1 attain still greater dimensions. Most of the dykes in quarries Nos. 1 and 2, unlike those elsewhere on the island, are crushed, and these, being more susceptible to erosion than the adjoining limestone, are marked by shallow ravines which are partly filled by limestone blocks fallen from their walls. The dykes do not, therefore, outcrop except on the quarry-walls and on the sea cliffs. Some, at least, of these dykes may have been intruded prior to the quartz diorite and it is possible, therefore, that the crushing, like the folding and faulting in the limestone, accompanied the intrusion of the stock. One easterly-trending greenstone dyke cuts both quartz diorite and limestone west of No. 1 quarry.

The quartz diorite outcrops along the shore west of No. 1 quarry for a distance of more than 2,500 feet, and extends inland for a maximum distance of about 750 feet.

It is clearly responsible for the recrystallization of the limestone around its borders and may be responsible for much of the folding and faulting in the same area.

Overburden is thin or missing over much of the area, except in the ravines and hollows on the sites of crushed greenstone bodies.

The limestone is fine-grained and black in No. 5 quarry, more than 2,000 feet from the nearest outcrop of quartz diorite, but along the shore and in the other quarries the limestone is grey and medium- to coarse-grained. The grain-size of the limestone becomes, in general, progressively greater towards the quartz-diorite stock until within a few feet of this intrusive individual crystals of calcite reach 1½ inches in diameter. Magnesian beds have, however, resisted this recrystallization and even adjacent to the quartz diorite are relatively fine-grained.

Fine-grained white-rock, similar to that occurring in the Pacific Lime Company's quarries, has been recovered from a local occurrence 1,500 feet south of No. 5 quarry.

Analyses.—Samples were made up of uniform chips at the specified intervals across specified distances. In Nos. 2 and 5 quarries and in the shore cliffs east of No. 2 quarry the stratification was not sufficiently apparent for sampling to be related to the stratigraphic section. For this reason, a continuous succession of samples was taken along the shore cliffs and quarry-faces which, in general, trend north-westerly, cutting across stratification at an oblique angle. Therefore the distances across which these samples were taken probably are considerably greater than the stratigraphic thickness of beds represented in them. In quarries Nos. 3 and 4, where stratification was apparent, the samples were taken across the beds, and the distances measured are the stratigraphic thickness of beds represented.

Length.	Insol.	R_2O_3.	Fe_2O_3.	MnO.	MgO.	CaO.	P_2O_5.	S.	Ig. Loss.	H_2O.
*No. 4 Quarry.**										
Top of section at west end of quarry—										
30 feet	0.24	0.65	0.02	0.008	1.93	52.66	0.013	0.03	44.55	0.04
30 feet	0.48	0.97	0.11	0.009	2.79	52.16	0.017	0.07	43.34	0.06
30 feet	0.44	3.13	0.06	0.008	5.24	50.15	0.008	0.03	41.31	0.05
30 feet	0.44	1.08	0.06	0.007	4.47	52.98	0.013	0.04	41.18	0.01
Base of section at east end of quarry.										
*No. 3 Quarry.**										
Top of section—										
30 feet	0.50	0.74	0.11	0.059	2.11	52.67	0.013	0.04	43.56	0.05
30 feet	0.38	0.61	0.07	0.023	2.68	52.26	0.013	0.05	43.64	0.04
30 feet	0.44	1.19	0.10	0.008	4.23	51.76	0.017	0.05	42.08	0.05
Fault.										
30 feet	0.30	0.49	0.19	0.012	2.83	53.68	0.020	0.08	42.25	0.06
30 feet	0.64	0.14	0.28	0.018	0.83	53.47	0.017	0.09	44.32	0.04
30 feet	1.68	1.03	0.15	0.020	9.05	47.12	0.011	0.04	41.09	0.06
30 feet	0.50	0.66	0.19	0.014	1.92	53.58	0.015	0.08	43.00	0.05
Base of section.										
No. 2 Quarry.†										
West end of sampled section—between No. 2 and No. 1 quarries opposite the compressor-house—										
100 feet	0.48	0.17	0.11	0.041	1.77	54.31	0.008	0.03	43.48	0.03
Dyke at west end of No. 2 quarry—										
20 feet	0.20	0.11	0.18	0.026	2.82	54.08	0.017	0.04	42.61	0.07
50 feet	0.20	0.13	0.05	0.006	0.60	55.86	0.019	0.01	43.00	0.06
15 feet	0.20	0.15	0.06	0.007	0.50	55.75	0.008	0.03	43.30	0.04
50 feet	0.10	0.16	0.03	0.007	0.56	55.54	0.008	0.03	43.70	0.07
50 feet	0.50	0.34	0.05	0.010	0.68	55.43	0.006	0.01	42.61	0.07
50 feet	0.34	0.14	0.05	0.009	0.53	55.75	0.006	0.02	43.06	0.06
50 feet	0.18	0.14	0.05	0.012	0.68	55.43	0.006	0.02	43.40	0.04
50 feet	0.36	0.23	0.04	0.005	0.50	55.54	0.005	0.03	43.25	0.08
40 feet	0.50	0.35	0.05	0.008	0.29	55.54	0.004	0.01	43.04	0.07
50 feet	0.50	0.32	0.08	0.012	1.30	54.39	0.005	0.04	43.40	0.06
45 feet	0.40	0.20	0.05	0.013	0.65	55.54	0.006	0.01	43.00	0.08
East end of No. 2 quarry, July, 1944.										
Shore Cliffs East of No. 2 Quarry.‡										
100 feet	0.30	0.28	0.03	0.006	0.56	55.65	0.007	....	42.96	0.05
100 feet	0.30	0.17	0.03	0.004	0.40	35.75	0.007	....	43.20	0.04
100 feet	0.24	0.15	0.04	0.003	0.36	55.98	0.007	0.03	43.22	0.09
40 feet	0.34	....	0.02	0.003	0.33	56.00	....	0.02	43.42	0.08
East end of sampled section.										
No. 5 Quarry.†										
70 feet	0.36	0.44	0.09	0.014	1.30	55.23	0.007	0.03	42.33	0.04

* Samples consist of chips taken at intervals of 3 feet.

† Samples consist of chips taken at intervals of 5 feet.

‡ Samples consist of chips taken at intervals of 10 feet.

Development and Operation.—Quarrying in this area was commenced in 1933 by F. J. Beale, who had previously operated the Powell River Company's quarry at Marble Bay. Subsequently Beale sold the property to Beale Quarries, Limited, who have continued the operation of the deposits under the management of Balfour Guthrie & Company (Canada), Limited. Quarry No. 1 was abandoned because of the excessive amount of greenstone encountered in it, and Nos. 3 and 4 because of inferior grade of limestone. Quarry No. 5, although containing high-quality rock, is not being worked, partly because of the distance to the loading facilities. Work is, therefore, being confined to No. 2 quarry which in July, 1945, had a single face approximately 750 feet long and up to 100 feet high, which had been advanced inland up to 200 feet from its initial position.

Down holes and lifters are drilled by air-drills and about 10,000 tons of limestone broken in a single round every few months. Larger blocks were formerly broken by plug and feathers (*see* Goudge, 1933, p. 135), but more recently by plugging and bulldozing.

Blocks of limestone greater than 9½ inches in diameter and small enough to be moved by hand are shipped as " man-rock " directly to pulp-mills. This rock is loaded into trucks by means of a 1-cubic-yard Diesel shovel and dumped across a 5½-inch grizzly and the oversize dropped and the undersize taken to the mill for grinding.

During calm weather the oversize is dropped directly from the grizzly to a scow. During stormy weather the scow is kept at Sturt Bay, and the oversize rock is stockpiled adjacent to the loading-point. When weather is suitable, the scow may be brought to the dock and loaded in one or two days. A tug is maintained by the company to tow the scow from the quarry wharf to Sturt Bay at any time during the day if a storm develops, or in the routine operation to tow the scow to shelter each evening and to return it to the quarry-site next day or when weather permits. In this way it is possible to carry on loading on an exposed shore-line and at the same time provide adequate shelter for scows. Rarely even during the winter are loading operations held up for more than a few days by a continuous period of stormy weather.

Ground limestone, prepared from rock less than 5½ inches in diameter, is crushed in an 18- by 24-inch jaw-crusher breaking to 3 inches, and ground by a Jeffrey hammermill in circuit with a 20-mesh vibrating screen. Undersize goes by conveyer-belt to bins. The capacity of this plant for a minus 20-mesh product is about 10 tons per hour.

An older plant at the property consists of an 8- by 12-inch jaw-crusher, a Sturtevant ring-roll pulverizer, and hammer screen. The latter is used to prepare various products from minus 20 to minus 100 mesh in fineness. The capacity of this plant producing minus 20-mesh material is about 4 tons per hour, and minus 100-mesh material about 1 ton per hour.

Ground limestone is shipped in 100-lb. capacity paper bags loaded on scows at the plant.

Johnson Quarry.

Location and Accessibility.—The Johnson quarry is situated about 1,000 feet south 15 degrees west of the outlet of Priest Lake near the boundary of Lots 69 and 492. It is about 2 miles by road from the wharfs and harbours of Sturt Bay and Vananda Cove.

Geology.—The quarry lies in the second member of the Marble Bay formation at an undetermined distance above its base. The succession exposed in the quarry is made up of calcium limestone interbedded with minor amounts of magnesian limestone. The strata in the western part of the quarry dip westward at angles of from 12 to 22 degrees, the strata in the south-eastern part dip southward at 6 degrees.

One dyke striking north 60 degrees east is exposed at the south-western corner of the quarry.

Overburden is light adjacent to the quarry.

The rock is grey and moderately fine-grained.

Analyses.—Analyses of the limestone are as follows:—

	Insol.	R_2O_3.	Fe_2O_3.	MnO.	MgO.	CaO.	P_2O_5.	S.	Ig. Loss.	H_2O.
Upper 12 feet	1.00	0.24	0.13	0.027	3.84	50.87	0.014	0.04	44.19	0.01
Lower 15 feet	1.92	0.20	0.20	0.019	1.02	52.16	0.017	0.04	43.57	*Nil*

Development and Operation.—The quarry was opened and operated during 1945 by Stanley Beale, of Vananda, to supply pulp rock for the Powell River Company. The quarry was equipped with compressor and air-drill. Broken rock was loaded by hand into steel pans which were hoisted and dumped into a truck and the limestone conveyed to the Powell River Company dock at Sturt Bay. Three men were employed on the operation in July, 1945. At that time the quarry was about 60 feet in diameter and with a face up to 30 feet high. The operation is reported to have been abandoned in the fall of 1945.

S. Beale Black-rock Quarry.

Location and Accessibility.—Stanley Beale's "black-rock" quarry is situated in Lot 25 and adjacent to the Iron Mines Road. It is only 1½ miles by road from the west coast of Texada Island, but no protected harbour suitable for shipping exists anywhere in its vicinity. The nearest harbour and wharfs are on the east coast of the island at Vananda and Sturt Bay, each 3½ miles by road to the north.

Geology.—The quarry lies in the upper part of the first member of the Marble Bay formation a few hundred feet at most above the base of the limestone succession. Several joints dipping about 10 degrees to the north and similar to the bedding-fractures at the Pacific Lime Company's quarries at Blubber Bay are conspicuous in the quarry. No other indication of stratification is evident.

One dyke of undetermined thickness, striking south 20 degrees east and dipping 80 degrees west, forms the east wall of the quarry.

Overburden is light.

The rock is fine-grained and black, closely resembling the black limestone of Blubber Bay.

Analyses.—Analyses of the limestone in the quarry are as follows:—

Strata bounded by "bedding-fractures."	Insol.	R_2O_3.	Fe_2O_3.	MnO.	MgO.	CaO.	P_2O_5.	S.	Ig. Loss.	H_2O.
Top 9 feet	0.20	0.15	0.03	0.010	0.43	55.30	0.022	0.03	43.66	0.01
Middle 6 feet	0.44	0.17	0.02	0.005	0.40	55.30	0.015	0.04	43.36	0.01
Lowest 4.2 feet	0.50	0.14	0.05	0.007	0.43	55.20	0.006	0.04	42.27	0.02

Development and Operation.—Lot 25 is owned and the quarry has been opened and periodically worked by Starley Beale, of Vananda. In July, 1945, the quarry-face was 35 feet across, 15 feet high, and had been advanced 40 feet from its initial position.

White-rock Deposits.

The mode of occurrence of white-rock has already been mentioned (page 73). It apparently consists, for the most part at least, of dark limestone bleached by solutions which have permeated along fractures and soaked into adjacent rock. Most of these fractures are no longer open, hence the bleaching is evidently not related to the existing solution channels or to the present land surface. Workable deposits exist at any place in which extensive fracturing has been accompanied by sufficient bleaching to create a body of white-rock large enough and free enough from residual masses of darker limestone to permit economic quarrying and marketing. Impurities, other than iron, which might stain the rock, and dark minerals, are not detrimental.

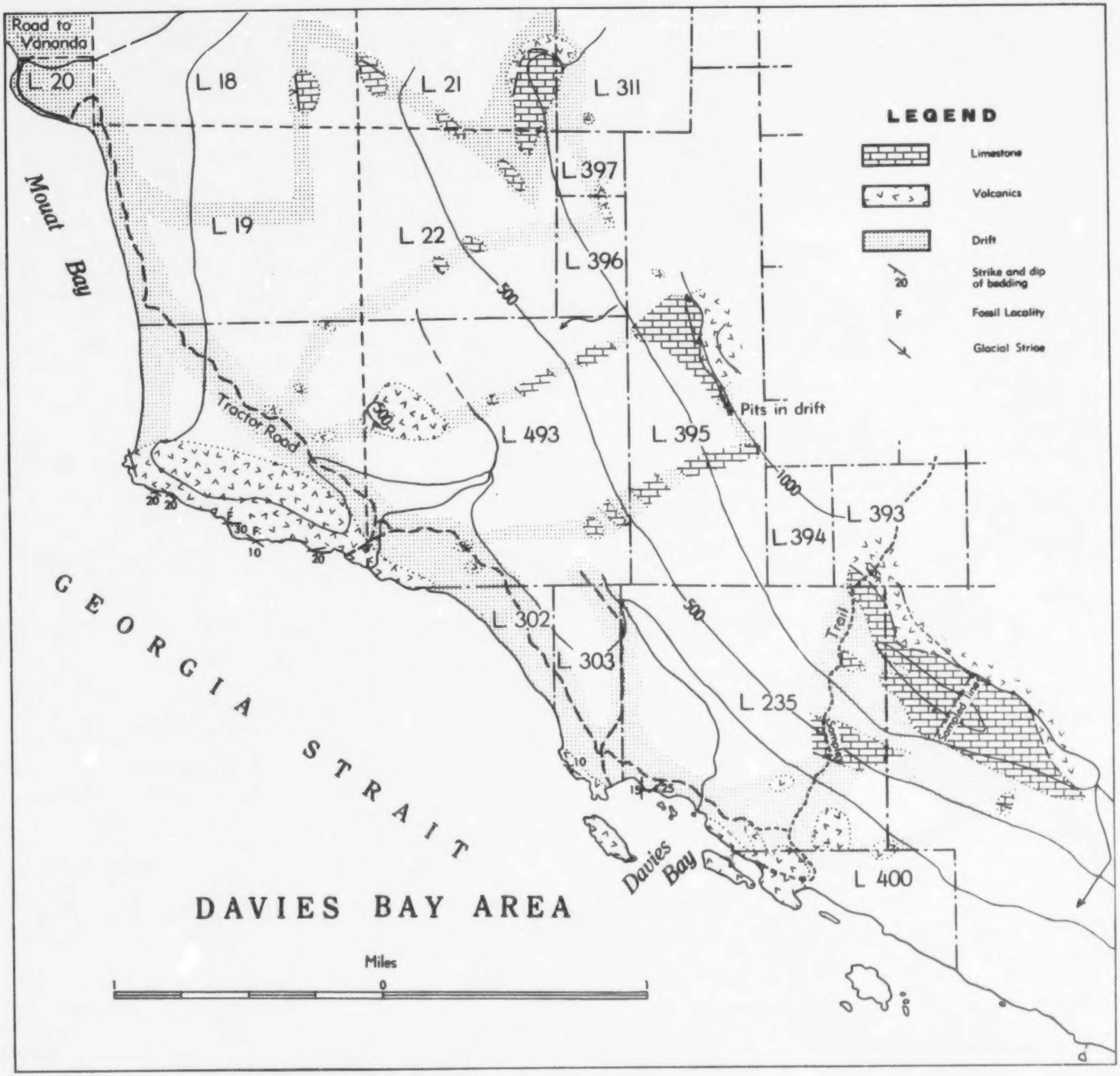
Road to Vananda
L 20
L 18
L 21
L 311
L 397
L 396
L 19
L 22
L 493
L 395
L 393
L 394
L 302
L 303
L 235
L 400
Mouat Bay
Tractor Road
Pits in drift
Trail
Davies Bay
GEORGIA STRAIT
500
1000
20
30
10
15
25
F
LEGEND
Limestone
Volcanics
Drift
Strike and dip of bedding
Fossil Locality
Glacial Striae
DAVIES BAY AREA
Miles
0

Figure 14.

The price per ton of clean white-rock is considerably higher than that of ordinary limestone. Therefore, deposits of white-rock smaller and more remote than any commercial deposit of ordinary limestone may be worked profitably. No very extensive bodies of clean white-rock are known on the island, but many smaller masses have been worked. White-rock has been produced by the Pacific Lime Company from the western part of Lot 13; by Coast Quarries, Limited, from Lot 9; by B.C. Cement Company from a body on Lot 12 at the south-west contact of the gabbro-diorite stock on the shore of Blubber Bay; by Beale Quarries, Limited, from a body south of quarry No. 5; by S. Beale from Lot 423; and by various individuals from numerous points up to 1½ miles south and south-east of Vananda.

Some of the white-rock is shipped to Stucco Products, Limited, of Vancouver, and some to the Beale Quarries mill situated a few hundred feet east of the Vananda dock.

DAVIES BAY LIMESTONE-BELT.

Location and Accessibility.—A north-westerly-trending belt of limestone, 4 miles long and as much as 1 mile wide, exists near the west coast of Texada Island in the vicinity of Mouat (Lower Gillies) and Davies (Davie) Bays. It lies 10 to 15 miles south-east of Vananda, the nearest regular port of call for coastal steamers. Mouat Bay can be reached by road from Vananda and a tractor road exists between Mouat Bay and Davies Bay.

Mouat Bay has an exposed and shelving shore, and although the hulk of the old Canadian Pacific steamer "Princess Beatrice" has been beached there to serve as a breakwater for booming operations, no suitable shelter exists for tugs and scows. Davies Bay is well sheltered and though of limited size is suitable for tugs and scows if not for larger vessels.

Geology.—As stratification has been found nowhere in the limestone-belt, direct evidence of its relationship to the surrounding volcanic rocks of the Texada formation could not be determined. In view of similarity of this limestone in appearance and composition to the limestone on the northern part of Texada Island, it may, with little doubt, be referred to the Marble Bay formation overlying the Texada formation. The volcanic rocks exposed along the shore to the south-east of the limestone-belt strike easterly at a marked angle to the concealed limestone-volcanics contact. The limestone in this part appears, therefore, to be in a faulted relationship with the Texada formation to the west. Along the north-eastern edge and at the northern end of the limestone-belt, however, the main limestone body appears to be in conformable relationship with the volcanics, for at several places a bed of limestone a few feet across has been found in the Texada formation paralleling the contact with the main limestone body (*see* Fig. 14). The limestone body appears, therefore, to be a south-westerly-dipping block of the Marble Bay formation bounded on the west by a fault. A possible southerly-plunging fold is indicated at the north end of the belt by the form of the contact. The high-grade limestone of the lower part of the Marble Bay formation should, therefore, occur along the eastern edge of the belt and, as is shown by sampling, does so, at least near the south-eastern end. The angle of the dip and the thickness of limestone in the belt have not been determined, but calcium limestone similar to that in the second member of the Marble Bay formation farther north occupies the south-western half of the belt, hence possibly 1,000 feet of limestone may be present in some parts.

No dykes have been observed in the limestone and very few in the volcanics exposed along the shore between Mouat and Davies Bays.

Overburden is extensive in the western part of the limestone-belt and its depth along the eastern shore of Mouat Bay may exceed 150 feet. In most parts of the higher and more steeply sloping eastern half of the limestone-belt overburden is thin or missing. The projection of the eastern contact of the limestone-belt under a local cover of drift in the central part of Lot 395 is marked by a series of conical pits as much as 100 feet wide and 40 feet deep where the unconsolidated debris has apparently fallen through a central aperture into an underlying chamber, presumably in the limestone or along the limestone-volcanics contact. It is reported that prospectors once found one of these chambers accessible and descended into it in an unsuccessful search for ore, but so far as is known none of the chambers can now be reached.

Analyses.—Samples, each composed of chips taken at 25-foot intervals along a line 250 feet long, obtained from the southern end of the limestone-belt (*see* Fig. 14), have the following analyses:—

Distance from:	Insol.	R_2O_3.	Fe_2O_3.	MnO.	MgO.	CaO.	P_2O_5.	S.	Ig. Loss.	H_2O.
South-western edge of exposure—										
0–250 feet	0.40	0.20	0.25	0.009	3.52	51.08	0.017	0.04	44.42	0.13
250–500 feet	0.20	0.01	0.13	0.004	3.66	51.38	0.093	0.03	44.54	0.08
500–650 feet	0.24	0.11	0.16	0.006	3.14	51.59	0.046	0.03	44.56	0.19
Drift-covered area about 500 feet wide.										
North-eastern edge of exposure—										
1.250–1,000 feet	0.24	0.42	0.11	0.006	1.70	53.38	0.011	0.06	43.96	0.07
1,000– 750 feet	0.18	0.40	0.07	0.004	1.00	54.45	0.010	0.03	43.93	0.07
750– 500 feet	0.30	0.19	0.06	0.003	1.22	54.45	0.013	0.04	43.88	0.05
500– 250 feet	0.30	0.06	0.07	0.006	2.98	52.31	0.028	0.03	44.32	0.13
250– 0 feet	0.42	0.12	0.10	0.006	0.74	54.35	0.014	0.03	43.91	0.04
Contact with Texada formation.										

Development.—No attempt has been made to quarry limestone in this area, although studies have been made of the deposit with a view to possible future production. The high-grade limestone outcrops at the north-eastern edge of the limestone-belt; it is approximately 1 mile from the one useable harbour, Davies Bay, but is free from dykes and favourably situated for a quarry and tramway.

Reference.

McConnell, R. G. (1914): Texada Island, B.C.—*Geol. Surv., Canada*, Mem. 58, pp. 90, 99.

OPEN BAY DEPOSITS.*

Location and Accessibility.—Limestone interbedded with volcanics occurs in a belt averaging ¾ mile wide extending north-westward from Open Bay on Quadra Island. Open Bay can be reached by boat from Heriot Bay 2½ miles to the south.

Open Bay is shallow and has a low irregular shore-line. No adequate shelter exists for tugs and scows from south-easterly gales, but a few small islets offshore provide a measure of protection. Good shelter for shipping can be obtained at Heriot Bay and Drew Harbour 2½ and 3 miles respectively to the south.

Geology.—The Open Bay deposits consist chiefly of argillaceous limestone interstratified with and overlying ellipsoidal and amygdaloidal lavas of the Texada formation. The lowest limestone member is poorly exposed at the west end of Open Bay but well exposed about 1 mile inland where it exceeds 100 feet in thickness. At the shore it dips about 30 degrees eastward and is overlain by about 350 feet of ellipsoidal and massive lava exposed on the first promontory from the west end of the bay. This is overlain by 50 feet or less of limestone which in turn is overlain by about 200 feet of lava exposed on the second promontory from the west end of the bay. Possibly as much as 500 feet of steeply dipping limestone, and at least one greenstone body, are incompletely exposed in the next bay to the east. East of this bay intensely folded argillaceous limestones and pillow lava are exposed in a belt about 2,000 feet wide bounded on the east by intrusive granitic rocks.

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* Maps and information collected by Prof. H. C. Gunning and undergraduate students in geology at the University of British Columbia were of assistance to the writer in the examinations of these deposits.

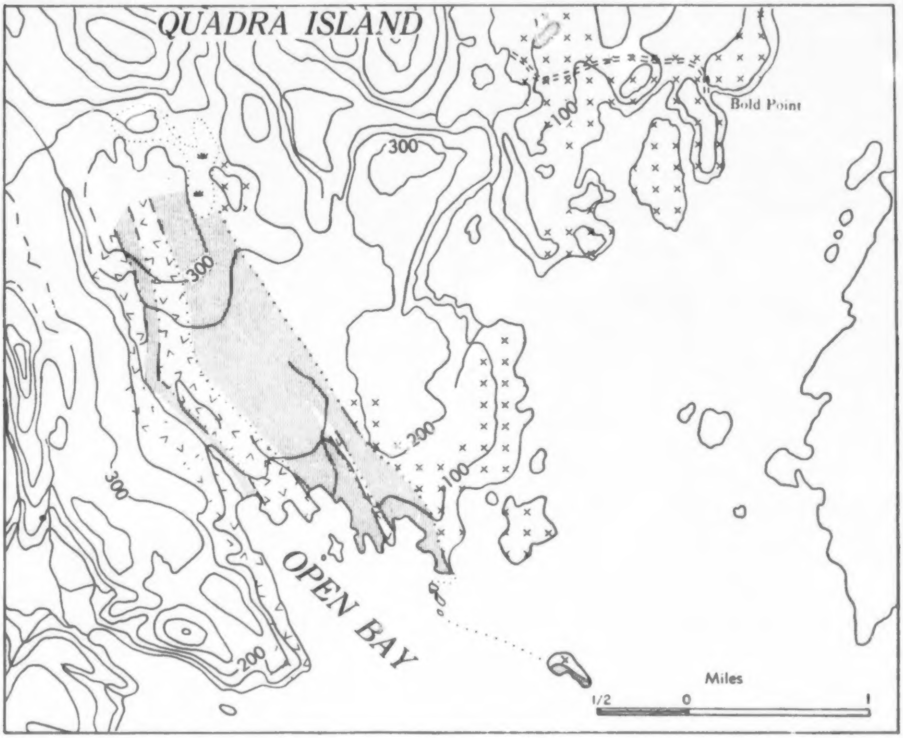

Fig. 15. Open Bay-Bold Point area, Quadra Island. Vertical ruling—limestone; pattern of v's—volcanics; pattern of x's—granitic rocks.

The prevailing dip of the bedded rocks is north-easterly throughout Open Bay. The extreme folding of the sediments in the eastern half of the bay, however, obscures the general structure, but the pillow lava interbedded with the argillaceous limestones, though folded itself, clearly conforms to this general north-easterly dip.

Dykes a few feet wide are present in parts of the area and lenticular sills a few inches to a few feet wide are common. The contact with the granitic rocks at the north-eastern edge of the belt is irregular in detail but follows in general a relatively straight line north-westerly across the island truncating the limestone-belt at an acute angle. For this reason the limestone-belt does not extend as far as Granite Bay (Bancroft, 1913; Cairnes, 1913, p. 58), on the opposite shore of Quadra Island, 8 miles north-west of Open Bay.

Overburden is scarce or absent on the low ridges extending inland from the bay, but is extensive and of undetermined depth in the valleys.

The limestone is in general black and granular and emits a distinct odour of hydrogen sulphide when broken. Fine laminæ of argillaceous impurities are distributed throughout the rock. Fossils found by Professor Gunning and students from the University of British Columbia near the west edge of the intensely folded belt are reported to be of Karnian (Upper Triassic) age (*see* page 36).

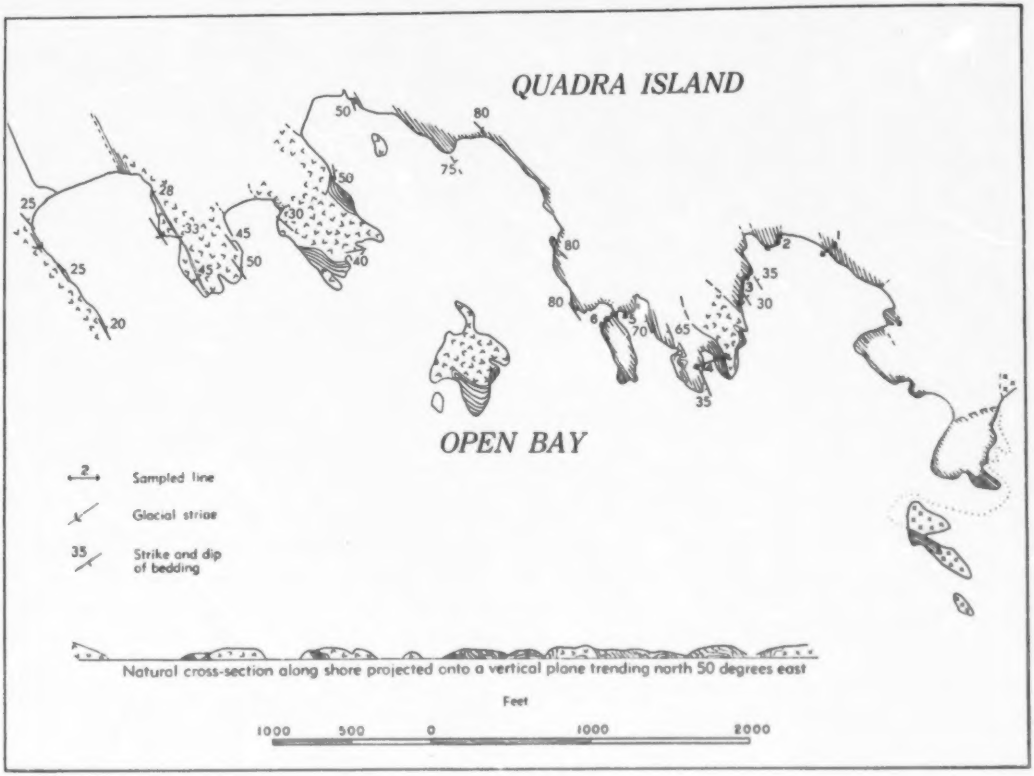
QUADRA ISLAND
OPEN BAY
Sampled line
Glacial striae
Strike and dip of bedding
Natural cross-section along shore projected onto a vertical plane trending north 50 degrees east
Feet
1000
500
0
1000
2000

Fig. 16. Open Bay area, Quadra Island. Pattern of lines—limestone; pattern of v's—volcanics; pattern of x's—granitic rocks.

Analyses.—Samples, each composed of up to 10 chips at 10-foot intervals measured across the strike of the limestone, were obtained from the lowest and westernmost limestone member, about 1 mile from Open Bay (Fig. 15), and across the north-eastern folded belt along the shore of Open Bay (Fig. 16).

Sample.	Insol.	R_2O_3.	Fe_2O_3.	MnO.	MgO.	CaO.	P_2O_5.	S.	Ig. Loss.	H_2O.
No. 1	12.44	0.78	0.05	0.006	0.32	47.29	0.090	0.24	38.54	0.06
No. 2	11.20	2.25	0.56	0.024	0.22	47.86	0.112	0.22	38.52	0.08
No. 3	13.28	1.70	1.03	0.023	0.06	46.18	0.131	0.45	37.00	0.11
No. 4	5.08	0.50	0.29	0.025	0.64	51.69	0.095	0.13	41.39	0.06
No. 5	15.72	1.08	0.70	0.008	0.40	44.94	0.119	0.25	36.54	0.32
No. 6	10.14	1.04	1.04	0.014	0.48	47.70	0.078	0.62	38.95	0.10
West edge of intensely folded belt.										
No. 7	1.66	0.16	0.14	0.018	0.32	54.04	0.041	0.06	43.27	0.01

Development and Operation.—Two test-pits were found in the steeply dipping limestones near the western edge of the folded belt on the shore of Open Bay, and a kiln exists near-by. Operations were evidently abandoned before more than a few tens of tons had been quarried.

The limestone in the upper part of the section is high enough in insoluble matter to be unsuited for anything except, perhaps, the manufacture of cement. There is no adequate shelter for shipping and the comparatively low elevation of the ground would prohibit the development of a high quarry-face above water-level anywhere adjacent to the shore.

The lowest belt of limestone is of better grade but where well exposed is fully 1 mile from tide-water.

References.

Bancroft, J. A. (1913): Geology of the coast and islands between the Strait of Georgia and Queen Charlotte Sound, B.C.—*Geol. Surv., Canada,* Mem. 23.

Cairnes, D. D. (1913): The lime belt, Quadra (South Valdes) Island, B.C.—*Geol. Surv., Canada,* Sum. Rept. for 1913, pp. 58–75.

LIMESTONE IN THE CAMPBELL RIVER AREA.

Limestone occurs at several places from 16 to 20 miles west and south-west of Campbell River on Vancouver Island. According to Gunning* "limestone outcrops on the north-central shore of Upper Campbell Lake and continues north beyond the 50th parallel, outcropping in Greenstone Creek about 3 miles above its mouth. A few remnants of the same bed are found capping knolls along the west contact of the Quinsam granodiorite, south of Upper Campbell Lake, and what is presumably the same horizon is in part replaced by magnetite ore on the Iron Hill claim just south of Upper Quinsam Lake. What may be a continuation of this horizon to the south-east was encountered on the west fork of Oyster River 16 miles south of the 50th parallel." These deposits, which overlie a thick succession of volcanics of the Vancouver series, and which apparently underlie a succession of highly folded impure limestones, argillites, quartzites, and volcanic rocks of Upper Triassic age, are believed to correspond to the Marble Bay formation of Texada Island. Although logging roads and railways have been built to many of these localities mentioned above, their remoteness from the Georgia Strait probably precludes early development of these deposits.

"SUTTON" LIMESTONE-DEPOSITS OF THE SAANICH PENINSULA AND MALAHAT DISTRICTS.

GENERAL.

The limestone-deposits of the Saanich Peninsula and the Malahat and Cowichan Lake districts can be readily distinguished from those occurring elsewhere in the Georgia Strait area. These so-called Sutton limestones have been mapped as part of the Vancouver series by Clapp (1912, 1913, 1917). The age of the Sutton limestone is now placed as Upper Triassic, on the basis of fossils found in a limestone body at Cowichan Lake (McCann, 1922; Martin, 1916). The Cowichan Lake deposits are not discussed further in the present bulletin. The limestone-deposits of the Saanich and Malahat districts have yielded no fossils and are clearly distinct in structure, though perhaps not in age, from the Triassic deposits elsewhere in the area.

The limestone-deposits occur in an area underlain predominantly by greenstones, dense, fine-grained, in places porphyritic, and generally devoid of megascopic structures, such as stratification. In a few places the greenstone has a fine-banded structure and these rocks may have been derived from tuffs. None of these banded greenstones have, however, been found in close association with the limestone.

The limestone bodies occur as irregularly elongated masses, generally of small extent although one exceeds 1 mile in length and ¼ mile in width. Wherever the margins of the limestone bodies are exposed they are found to be steeply dipping.

Many tabular to lenticular bodies of greenstone are found within the limestone-deposits. These bodies are in general parallel to one another, to banding and possible stratification in the limestone, and the strike and dip of the deposits themselves. The margins of the greenstone bodies are either faulted or are irregular in detail; unlike those of dykes and sills which occupy clear-cut fractures, some of the bodies pinch out or terminate in bulbous ends within the limestone. No conclusive evidence of the origin of these greenstone masses have been found, but the existing data favour their interpretation as flows. Clearly defined greenstone dykes cutting across the prevailing trend of a deposit area are rare. In a large part of the Saanich and Malahat districts, however, the limestones and greenstones are intruded by a complex system of dykes and irregular masses ranging in composition from diorite to granodiorite, and including possibly gabbroic phases.

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* Gunning, H. C. (1930): Buttle Lake map-area, Vancouver Island—*Geol. Surv., Canada,* Sum. Rept. for 1930, Pt. A, p. 62.

Sections measured across the full width of the limestone-deposits show very marked variations from place to place. Some parts of a deposit are free from magnesian impurities, others may be made up predominantly of magnesian limestone. Similarly some parts are almost free from sill or flow-like bodies of greenstone, in other parts only a few hundred feet away and along strike these may predominate. An original lenticular character of limestone-deposits incorporated in a succession of lavas may be responsible for most of these variations, while strike faulting and transverse faulting presumably complicate the sections.

In a few cases, notably at Tod Inlet, a series of limestone bodies, *en échelon*, in a single belt, may represent a single limestone horizon repeatedly offset by transverse faulting. In other cases the limestone horizon may be terminated against intrusive bodies, interrupted by tight folds; or where the drift-cover is fairly extensive, discontinuities may be more apparent than real.

References.

Carmichael, H. (1911): Limestone deposits of the coast—*Minister of Mines, B.C.*, Ann. Rept. for 1911, pp. 204–209.

Clapp, C. H. (1912): Southern Vancouver Island—*Geol. Surv., Canada*, Mem. 13, pp. 61–71.

——— (1913): Geology of Victoria and Saanich map-areas—*Geol. Surv., Canada*, Mem. 36.

——— (1917): Sooke and Duncan map-areas—*Geol. Surv., Canada*, Mem. 96.

McCann, W. S. (1922): Geology and Mineral Deposits of the Bridge River map-area—*Geol. Surv., Canada*, Mem. 130.

Martin, G. C. (1916): Triassic Rocks of Alaska—*Geol. Soc. Am.*, Bull. 27, pp. 685–718, 1916.

DESCRIPTION OF PROPERTIES.

Bamberton Deposit.

Location and Accessibility.—The Bamberton limestone-deposits of the British Columbia Cement Company are situated on the west side of Saanich Inlet in Lots 73 and 95. They lie less than 1 mile by road from the Island Highway and about 25 miles by road from Victoria. Wharfs and loading facilities are within a few hundred feet of the quarry.

Geology.—The Bamberton limestone-deposits consist of one or more limestone members intimately associated with tabular bodies of greenstone of uncertain origin. Stratification has not been recognized in the deposit except near the north-western corner of the upper part of the main quarry (*see* Fig. 17), where alternating magnesium-rich and calcium-rich beds strike south 60 degrees east and dip 70 degrees north-eastward. At places throughout the main quarry, however, a faint banding in the limestone has a similar strike and dip, and so have a conspicuous joint pattern, many faults, and most of the tabular greenstone bodies. The aggregate thickness of limestone exceeds 500 feet in the section across and to the north-east of the face of the lower bench in the main quarry. In this section the rock consists dominantly of high-calcium limestone in the lower or south-western part, and of magnesian limestone in the upper or north-eastern part beyond the limit of the quarry (*see* analyses).

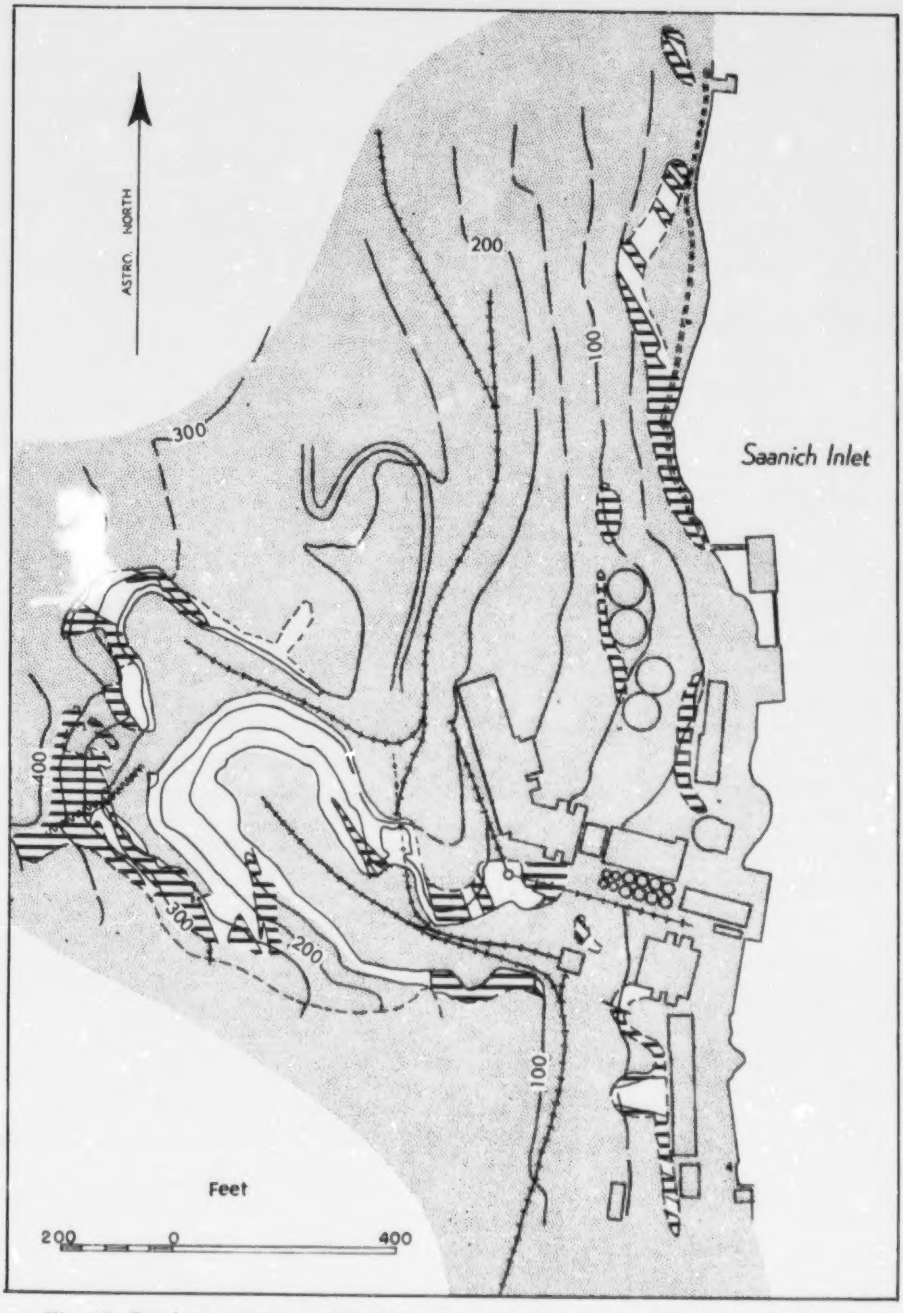
ASTRO. NORTH
Saanich Inlet
300
200
100
400
300
200
100
Feet
200
0
400

Fig. 17. Bamberton Quarry area, Vancouver Island. Blank—limestone; horizontal bars—greenstone; oblique bars—rhyolite; stippling—geology concealed.

Greenstone bodies occupy a considerable proportion of the section across the limestone-belt 300 feet to the south-east of this face, and an aggregrate thickness of only about 250 feet of limestone is known to be present, most of which, however, is high-grade limestone. A decrease in the thickness of at least the high-calcium limestone of the south-western part of the belt also takes place between the face of the lower bench and that of the upper bench 200 feet to the north-west. The explanation of these changes in thickness is not evident. To the north-west of the main quarry a heavy cover of drift prevents measurement of the section, but limestone is known to continue for at least 500 feet.

An exposure of limestone and intercalated greenstone occurs on the shore of Saanich Inlet about ¼ mile north of the main quarry. Here banding in the limestone, conspicuous joints, and tabular bodies of greenstone strike about south 50 degrees east and dip 50 degrees south-west. A total thickness of about 350 to 400 feet, measured at right angles to the prevailing attitude, is present in this exposure, of which possibly not more than one-half is limestone.

The greenstone bodies within the limestone at both the above-mentioned localities vary from a few inches to at least 50 feet in thickness. Most are lenticular, bounded on one or both sides by faults. The greenstone is dense, fine-grained, and devoid of such megascopic features as bedding, banding, amygdules, flow or ellipsoidal structures, which might give a clue to their origin. Swanson* reports finding in a thin section of one specimen of porphyritic greenstone from the quarry a vague spherulitic texture in the altered fine to very fine grained matrix. He interprets this rock as being " in part a devitrified glass," and suggests that it may have been a glassy flow or possibly a tuff. The general parallelism of the greenstone bodies to one another and to the banding as well as to the one case of stratification within the limestone also suggests that they may be sills, flows, or beds. The opposing dips of the greenstone bodies in the main quarry and in the exposures on the shore ¼ mile to the north suggest that they have been folded at some time following their emplacement. Greenstone dykes, cutting across the prevailing trend of the rocks at marked angles, are known but are small and few in number.

At least one body of light green to white rhyolite occurs at the mouth of the lower level of the main quarry, and another at the north-western end of the upper level.

The igneous rocks mentioned have been utilized as a source of silica, alumina, and iron for the cement plant. Not all of these rocks, therefore, have had to be segregated from the limestone, and discarded. In view of their economic importance, a suite of specimens of the various igneous rocks was collected by the company and submitted to commercial analysts for chemical analysis and petrographic study, the latter work having been carried out by Swanson. Two main groups of igneous rocks can, on the basis of their analyses, be clearly distinguished, one characterized by a low silica content, 35 to 50 per cent., the other by a high silica content, 70 to 74 per cent. In the former group belong the greenstones, consisting of laths of plagioclase feldspar now partly altered to sericite, carbonate, and kaolin, in a fine-grained matrix of chlorite, carbonate, sericite, and a small amount of quartz; epidote is present locally. These rocks have chemical compositions approximating those of altered basalts from other localities. In the high-silica group belong the rhyolites, consisting of phenocrysts of feldspar, and locally of quartz, in a fine-grained groundmass of quartz and alkali feldspar, now partly altered to sericite. Carbonate and iron oxides along fine veinlets as well as chlorite and epidote are present locally. The composition of the high-silica group approximates that of an average rhyolite.

Faults are common in the main quarry, and generally trend north-westerly and dip steeply to the north-east. A few transverse faults are also known, one, dipping steeply south-east along the western face of the upper part of the quarry, truncating the main belt of high-grade limestone. A second transverse fault at the mouth of the lower level of the main quarry is inferred from the presence of one or more rhyolite bodies (*see* above) and by an abrupt change in the trend of the greenstone bodies (*see* Fig. 17).

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* Swanson, C. O. (Professor of Mineralogy and Petrography, University of British Columbia): Unpublished report.

Overburden, consisting of stratified sands and gravels, silt, and glacial till, some of which contain very large boulders, covers most of the area adjacent to the quarries except on steep rocky bluffs which rise to the west and south-west of the main quarry. Many exposures of drift exceed 10 feet in depth, and an average thickness of at least several feet can be expected.

The limestone from the deposit is generally dark blue and fine-grained. It is only locally banded. White-rock is present but is not common.

Analyses.—Eight samples, each composed of chips taken at 6-foot intervals, were taken across the limestone-belt at the head of the lower quarry. The first two of them were beyond the confines of the quarry, the others from the top of the lower quarry-face as it existed in April, 1946. Greenstone was excluded from the samples but a pale green rhyolite(?), distinguishable only with difficulty from the limestone, was included in Sample 5.

Sample.	Insol.	R_2O_3.	Fe_2O_3.	MnO.	MgO.	CaO.	P_2O_5.	S.	Ig. Loss.	H_2O.
No. 1	1.4	Trace	0.420	0.072	11.80	42.2	0.009	0.033	44.9	....
No. 2	2.8	1.16	0.320	0.080	8.92	42.2	0.016	0.053	43.0	....
No. 3	Not accessible.									
No. 4	2.0	0.18	0.160	0.041	1.93	52.8	0.022	0.024	43.1	0.02
No. 5	32.5	1.00	0.760	0.022	0.39	24.9	0.030	0.069	20.3	0.03
No. 6	4.8	0.29	1.150	0.023	0.87	51.8	0.031	0.027	49.9	....
No. 7	1.1	0.08	0.087	0.016	0.40	54.8	0.021	0.024	43.3	....
No. 8	0.6	Trace	0.086	0.014	0.55	55 3	0.019	0.040	43.6	....
No. 9	1.1	0.28	0.370	0.030	0.55	54.7	0.024	0.140	43.0	0.07

Development and Operation.—The Bamberton deposits, formerly known as the Elford deposits, were worked at least as early as 1907 when limestone was quarried and burned by Elford & Company, but these operations had been abandoned by 1911. The Associated Cement Company then acquired the property, erected the present cement plant, and produced Portland cement from 1913 to 1917. In 1919 the Associated Cement Company and the Vancouver Portland Cement Company were amalgamated to form the present British Columbia Cement Company which recommenced operations at the Bamberton quarry and cement plant in 1921. The quarry and plant have been in continuous production since that time. In recent years a part of the limestone needed in the cement production has been obtained from the company's quarries on Texada Island.

Nearly all the limestone from the Bamberton deposits has been obtained from the main quarry, situated west of the plant, and from a small glory-hole adjacent to it, but some was obtained during the excavation for the plant buildings, some from two small quarries at the base of the hillside near the south end of the plant area, and some from the deposit exposed on the shore ¼ mile north of the plant.

The main Bamberton quarry is being worked at a lower and an upper level, 90 and 225 feet respectively above sea-level. The highest point on the quarry rim is about 410 feet above sea-level. No standard round is used in drilling the face with air-drills. Larger blocks of limestone or igneous rock are bulldozed when necessary.

Broken rock is loaded by means of a 25B and a 7B Bucyrus Erie electric shovel of 1-cubic-yard and ⅞-cubic-yard capacity respectively into narrow-gauge railway-cars of 5¾-ton capacity. A 4-ton Plymouth gasoline locomotive on the upper level hauls limestone and whatever igneous rock may be needed for the cement plant to the edge of the old glory-hole where this rock is dumped and loaded through the glory-hole chutes into cars on the lower level. These are taken by rope haulage to the crusher. Limestone from the lower bench is hauled by means of an 8-ton Plymouth locomotive.

Limestone, and the other rock required, is passed through an 8K gyratory crusher and two 5K gyratory crushers to a storage bin, thence to the ball-mills and mixers at the cement plant, which has a capacity rated at 900,000 barrels per annum.

All the limestone produced from deposits is consumed in the manufacture of cement.

References.

Carmichael, H. (1911): Limestone deposits of the coast—*Minister of Mines, B.C.*, Ann. Rept. for 1911, p. 207.

Clapp, C. H. (1912): Southern Vancouver Island—*Geol. Surv., Canada*, Mem. 13, pp. 61–71, 197.

——— (1917): Sooke and Duncan map-areas—*Geol. Surv., Canada*, Mem. 96, pp. 396, 397.

Brewer, W. M. (1926): *Minister of Mines, B.C.*, Ann. Rept. for 1926, pp. 334–337.

Tod Inlet Deposits.

Location and Accessibility.—Several limestone bodies occur on and near Tod Inlet, on the east side of Saanich Inlet, in Lot 15, Range 1 west, and Lots 14 and 15, Range 2 west, South Saanich Land District, and in Lot 23, Highland Land District. Tod Inlet is accessible by road from Victoria, 13 miles to the south, or by water for both small and large shipping.

Geology.—The deposits which reach 250 feet in width and 500 feet in length occur as a series of south-easterly-trending *en échelon* bodies in greenstone. Stratification observed in the body west of Tod Inlet strikes south 30 degrees east and dips 30 to 35 degrees south-westward; the attitude of stratification in the other bodies has not been determined.

Greenstone dykes are present.

Overburden is in some cases light, but the deposit at Butchart's Gardens is buried at its north end under a drift-cover many feet deep, and the deposit west of Tod Inlet is largely concealed by drift.

The limestone is blue, grey, or almost white, and fine-grained.

Development and Operation.—Limestone was quarried and burned at Tod Inlet prior to 1904. In that year the limestone-deposits were acquired by the newly formed Vancouver Portland Cement Company who erected a cement plant of 100,000-barrels-a-year capacity. This plant was, by 1907, expanded to a capacity of about 300,000 barrels a year. The Vancouver Portland Cement Company and Associated Cement Company, owning the cement plant at Bamberton on the west side of Saanich Inlet, were amalgamated in 1918 to form the British Columbia Cement Company. This company in 1921 transferred the cement production to the Bamberton plant and the Tod Inlet plant and quarries were closed.

Since the abandonment of these operations the buildings of the Tod Inlet plant have been used to house a small cement tile industry operated by the British Columbia Cement Company. One of the abandoned quarries was planted with ornamental flowers and has become a part of the now famous "Butchart's Gardens." A second quarry is now used as a reservoir. A third quarry, adjacent to the Tod Inlet plant, is flooded. The limestone-deposit west of Tod Inlet was never developed.

References.

Robertson, W. F. (1904): *Minister of Mines, B.C.*, Ann. Rept. for 1904, pp. 256–260.

Clapp, C. H. (1912): Southern Vancouver Island—*Geol. Surv., Canada*, Mem. 13, p. 197.

——— (1913): Geology of Victoria and Saanich map-areas—*Geol. Surv., Canada*, Mem. 36, pp. 134, 135.

Malahat Deposit.

Location and Accessibility.—The Malahat limestone-deposit is situated near the north-western edge of Block 201, 2½ miles by road south-west of Malahat Station, 20 miles north of Victoria on the Esquimalt & Nanaimo Railway. The deposit is 22 miles by road from Victoria.

Geology.—The limestone body, a north-westerly-trending belt in greenstone, is about 100 to 150 feet wide and several hundred feet long. Banding in the limestone dips steeply.

Greenstone lenses of uncertain origin occur parallel to the banding in the limestone.

Overburden is light.

The limestone is medium to fine-grained and grey to white.

Analyses.—Three samples have been taken by J. M. Cummings from this property, the first across 150 feet near the north-western end of the belt, the second, a composite sample, across 50 feet of the middle part of the belt, and a third across the quarry-face. The analyses of these samples are as follows:—

	Insol.	$R_2O_3+Fe_2O_3$.	MgO.	CaO.
No. 1	1.8	0.29	2.24	51.9
No. 2	2.2	0.32	0.80	53.3
No. 3	2.2	0.47	0.44	53.3

Development and Operation.—The deposit was worked by F. Jefford, of Victoria, during 1944 as a source of white-rock and sold to the British-America Paint Company at Victoria. In January, 1946, the quarry, which was then idle, was about 100 feet long, 40 feet wide and about 30 feet high. A considerable amount of off-colour limestone had been dumped at the mouth of the quarry.

Millstream Deposit.

Location and Accessibility.—A limestone-deposit occurs on Millstream Road in the Highland District, 2.5 to 2.9 miles north of Langford Station on the Esquimalt & Nanaimo Railway 8 miles west of Victoria.

Geology.—This deposit is reported to be 1,000 feet wide and 3,000 feet long (Clapp, 1917, p. 104) and is surrounded by greenstone and intrusive bodies. Part of the limestone is fine-grained, part recrystallized. This recrystallized limestone shows textural variations apparently related to stratification. This banding at one point near the south-west end of the deposit dips 40 degrees north-west, at another point in the southern of two old quarries the banding dips about 20 degrees south-east. Overburden is absent on knolls but deep in the intervening hollows.

Analyses.—The analyses of two samples, free of dyke-rock, each composed of a series of chips taken at 5-foot intervals across 50 feet in the northern quarry, are as follows:—

	Insol.	R_2O_3.	Fe_2O_3.	MnO.	MgO.	CaO.	P_2O_5.	S.	Ig. Loss.	H_2O.
North sample	3.3	0.27	0.089	0.017	1.97	52.7	0.010	0.002	41.4	0.32
South sample	0.5	0.04	0.200	0.004	3.08	52.1	0.013	0.025	43.8	0.14

Development and Operation.—Limestone is reported to have been quarried in the Highland District, probably from this deposit, prior to 1908. Two quarries, both abandoned, have been opened in this deposit, 2.9 and 2.7 miles respectively north of Langford Station. Each of these quarries has a curved face 60 to 100 feet long and up to 20 feet high. The remains of an old kiln can be found near the northern quarry.

Reference.

Clapp, C. H. (1913): Geology of Victoria and Saanich map-areas—*Geol. Surv., Canada,* Mem. 36, p. 396.

Atkins Road Deposit.

Location and Accessibility.—Limestone outcrops on Atkins Road adjacent to the Esquimalt & Nanaimo Railway 0.9 mile east of Langford Station and 7 miles west of Victoria, in Lots 105 and 1, Esquimalt Land District.

Geology.—Limestone is exposed over an area several hundred feet long and possibly 200 feet wide. It consists of fine-grained blue limestone containing light-coloured bands dipping steeply westward. Greenstone bodies of uncertain origin are closely associated with the limestone. The deposit is partly covered by a thick deposit of fluvioglacial sand and fine gravel.

Analyses.—Three samples have been obtained from this property, one consisting of chips taken at 6-foot intervals across 60 feet of the north and east face of a shallow pit, partly flooded; the second taken at 4-foot intervals for 60 feet east of this pit; and a third consisting of chips from scattered outcrops near the roadside a few hundred feet south of the pit. Dyke-rock was excluded in sampling. The analyses of these samples are as follows:—

	Insol.	R_2O_3.	Fe_2O_3.	MnO.	MgO.	CaO.	P_2O_5.	S.	Ig. Loss.	H_2O.
North and west face	0.6	0.08	0.087	0.010	0.11	55.2	0.014	0.017	42.6	0.14
East of face	1.9	0.10	0.110	0.012	0.16	54.6	0.029	0.016	42.9	0.14
Roadside	1.3	0.06	0.081	0.006	0.94	54.0	0.010	0.009	43.3	0.10

Development and Operation.—The deposit was worked for a few years following the erection of a sand-lime brick plant in 1907 by the Silica Brick & Lime Company (Robertson, 1907), and three small quarries north of the railway and one larger quarry south of the railway together with two sand-pits were opened. In 1946 a cement brick plant had been erected on the site of the old plant and was using sand and crushed gravel obtained from one of the old pits. This plant could be converted into a mill for crushing and grinding limestone from the adjacent deposits.

References.

Robertson, W. F. (1907): *Minister of Mines, B.C.,* Ann. Rept. for 1907, pp. 155–157.
Clapp, C. H. (1913): Geology of Victoria and Saanich map-areas—*Geol. Surv., Canada,* Mem. 36, p. 134.

Parsons Bridge Deposit.

Location and Accessibility.—A limestone-deposit occurs on the north-western slope of a knoll 0.2 mile south-west of Parsons Bridge at the head of Esquimalt Harbour. It is 6 miles by road from Victoria.

Geology.—The deposit is at least 100 feet wide and 200 feet long. The limestone shows a distinct banding, probably related to stratification, which shows marked variations in attitude. Greenstone bodies are present within the limestone. A granitic intrusive limits the deposit on the south-east and east. Overburden is absent on the upper part of the knoll but mantles the lower slopes where it covers the extension of the limestone-deposit to the west and north.

Analyses.—Two samples, free of dyke-rock, each composed of chips taken at 6-foot intervals, were taken across the face of the lower quarry and the adjacent slope to the south. The analyses of these samples are as follows:—

	Insol.	R_2O_3.	Fe_2O_3.	MnO.	MgO.	CaO.	P_2O_5.	S.	Ig. Loss.	H_2O.
Northern 60 feet	2.6	0.45	0.37	0.013	1.28	53.2	0.015	0.082	42.2	0.02
Southern 60 feet	1.9	0.38	0.28	0.017	0.90	53.7	0.009	0.057	42.6	0.14

Development and Operation.—The limestone of the deposit was originally quarried for flux by the Tyee Copper Company and later quarried and burned by the Victoria Lime Company for agricultural lime. Although the property was idle in the spring of 1946 the lime-burning plant was in operating condition.

Reference.

Clapp, C. H. (1913): Geology of Victoria and Saanich map-areas—*Geol. Surv., Canada*, Mem. 36, p. 135.

Rosebank Deposit.

Location and Accessibility.—The Rosebank limestone-deposit is situated west of Esquimalt Harbour in Lots 96 and 1, Esquimalt Land District. The main quarries are situated about 2,000 and 3,000 feet respectively west of the shore of Esquimalt Harbour and were formerly reached from it by means of a narrow-gauge railway. The deposit is 7 miles by road from Victoria.

Geology.—The limestone occurs in a belt at least 1¼ miles long and about ¼ mile wide. The belt is bounded on both north-east and south-west by greenstone. The limestone is grey and fine-grained; banding is present in many places and this, together with a distinct fracture cleavage, strikes north-westerly and dips at angles of 70 degrees or more, generally to the north-east. In one place two sets of fracture cleavage intersect to give rise to vertical splinters of limestone. Bodies of greenstone of uncertain origin are present in the limestone in addition to well-defined dykes.

The limestone is, in general, exposed and has been quarried only on a series of small knolls. The intervening hollows are covered by 5 feet or more of overburden.

Development and Operation.—The quarries are from one to several hundred feet in diameter and have been worked to a maximum depth of about 50 feet below the surface. These operations, carried on originally by Raymond & Sons and later by the Rosebank Lime Company, were started prior to 1907 and continued until about 1932. At one stage three lime-kilns were being operated. Since 1932 the property has been acquired by the Department of National Defence.

Reference.

Clapp, C. H. (1913): Geology of Victoria and Saanich map-areas—*Geol. Surv., Canada*, Mem. 36, p. 134.

LIMESTONE IN THE PARSONS BAY FORMATION.

No workable deposits of limestone are known to occur in the Upper Triassic Parsons Bay formation but the presence of calcareous material has been noted by Dawson, Bancroft, and McLellan.

HERNANDO ISLAND.

Bancroft* describes the rocks of the Parsons Bay formation occurring at Hidalgo Point on Hernando Island, in the northern part of the Strait of Georgia, as follows:—

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* Bancroft, J. A. (1913): Geology of the coast and islands between the Strait of Georgia and Queen Charlotte Sound, B.C.—*Geol. Surv., Canada*, Mem. 23, p. 76.

"In this locality the stratified series, which comprises cherty argillites, quartzites, numerous intercalated sheets of intrusive (?) greenstones, and a layer of blue limestone which is four inches in thickness, are intersected by numerous dark dikes. They occupy a very small area, being intruded by granodiorite and olivine-gabbro which cuts them off on every side except the northern."

TWIN ISLANDS.

Bancroft[*] reports that: "On Iron Point, on Twin islands, about two miles (N. 50° W.) from Hidalgo point, a small patch of stratified rocks occurs in which thin limestone layers are numerous, alternating with argillites and quartzites. They frequently contain garnet, pyrite, and occasionally a little magnetite, the presence of the last two minerals causing them to weather in brilliant red and in black colours. Their dip is 25° toward the northeast, while their strike is N. 54° W. Some of the limestone beds contain geodes lined with calcite, the formation of which may have been due to the presence of shells. A very imperfect cast of a pelecypod was found in a layer of impure limestone, which, from its convex shape and the character of its ribs and ear, is believed to be the right valve of distorted *Pseudomonotis subcircularis*."

DAVIDSON HEAD.

Limestone is reported by McLellan[†] in the Haro formation of Davidson Head, San Juan Island, in rocks believed to be the equivalent of the Parsons Bay formation. He states that the conglomerates which make up the lower part of the section exposed at this locality "are overlain by thin-bedded carbonaceous shale, slate, graywacke, grit, and limestone. The layers of limestone are interbedded with carbonaceous shale and the individual strata do not exceed four feet in thickness. The uppermost strata are largely concealed by glacial drift. . . ."

LIMESTONE-DEPOSITS OF UNCERTAIN AGE ENCLOSED IN GRANITIC ROCKS.

GENERAL.

Medium-sized to small deposits of limestone completely surrounded by areas of granitic rock occur on and near the north-eastern shores of the Georgia Strait. Some of the deposits, such as those at Bold Point and Dinner Rock, may be inclusions or roof pendants of the Marble Bay formation, others may be part of the Palæozoic succession; but, in general, too little is known of these deposits to permit correlation with the other deposits in the Georgia Strait area.

Only three of the deposits are known to have been worked for their limestone content—these have been examined either by the writer or by J. M. Cummings, of the British Columbia Department of Mines. Information on the others has been obtained entirely from the published reports by G. M. Dawson, J. A. Bancroft, O. E. LeRoy, J. M. Cummings, and E. M. J. Burwash.

DESCRIPTION OF OCCURRENCES.

PRYCE CHANNEL DEPOSIT.[‡]

"Upon the mainland, almost directly opposite (the Redonda Island deposits), it is reported that marble is exposed in the bed of a stream which enters Pryce channel about three-quarters of a mile west of Elizabeth island."

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[*] Bancroft, J. A. (1913): Geology of the coast and islands between the Strait of Georgia and Queen Charlotte Sound, B.C.—*Geol. Surv., Canada*, Mem. 23, p. 76.

[†] McLellan, R. D. (1927): The Geology of the San Juan Islands—*Univ. Wash.*, Publ. in Geol., Vol. 2, p. 112.

[‡] Bancroft, J. A. (1913): Geology of the coast and islands between the Strait of Georgia and Queen Charlotte Sound, B.C.—*Geol. Surv., Canada*, Mem. 23, pp. 66, 67.

REDONDA ISLAND DEPOSITS.*

Location and Accessibility.—Limestone occurs on the precipitous northern shore of West Redonda Island about 1½ miles west of George Point and a few hundred feet west of the north-west corner of Lot 3439. The deposit can be reached only by boat. According to Brewer (1919) "there are no beaches, sheltered coves, or anchorages where vessels could lie safely in the neighborhood, except on the opposite or north side of Pryce Channel."

Geology.—Limestone on Redonda Island occurs apparently as inclusions in the prevailing granitic rocks. Two deposits are exposed on the shore, both about 100 feet across and one at least extending southerly up the steep hillside for a minimum of 200 feet. The latter body is cut by several dykes. Other smaller bodies are reported on the Elsie and Eagle Mineral Claims, ½ mile north-west and ¼ mile west respectively. Goudge (1946) refers to the presence of brucite and of dolomite in the limestone at the quarry. He found the average brucite content to be low, but his sample across a width of 20 feet, in which a concentration of brucite occurs, was found to contain 20.5 per cent. magnesium oxide.

Analyses.—The analyses of three samples taken in the quarry by Mr. Cummings are as follows:—

Sample.	Insol.	R_2O_3.	Fe_2O_3.	MnO.	MgO.	CaO.	P_2O_5.	S.	Ig. Loss.	H_2O.
No. 1	1.8	0.23	0.17	0.014	2.60	52.5	0.012	0.080	42.9	....
No. 2	1.7	0.40	0.25	0.019	6.24	48.4	0.015	0.090	42.9	0.06
No. 3	6.6	0.72	0.24	0.035	4.28	48.3	0.012	0.030	39.8	....

Development and Operation.—The easterly of the two limestone bodies exposed on the shore was quarried in 1920 by the Nickson Construction Company, who shipped 8,450 tons of limestone to the Whalen Pulp & Paper Company. This deposit was also worked in 1926 but there is no record of any work having been done on it since that time. In 1938 the quarry was about 200 feet long from north to south, about 100 feet high, and the face reached an elevation of more than 100 feet above the water.

References.

Bancroft, J. A. (1913): Geology of the coast and islands between the Strait of Georgia and Queen Charlotte Sound, B.C.—*Geol. Surv., Canada*, Mem. 23, p. 78.

Brewer (1919): *Minister of Mines, B.C.*, Ann. Rept. for 1919, p. 215.

——— (1920): *Minister of Mines, B.C.*, Ann. Rept. for 1920, p. 216.

Goudge, M. F. (1946): Limestones of Canada, Part V. Western Canada, *Bureau of Mines*, Department of Mines and Resources, Canada, pp. 161–163.

Young, G. A., and Uglow, W. L. (1926): Iron Ores of Canada, Vol. I., British Columbia and Yukon—*Geol. Surv., Canada*, Ec. Geol. Ser. No. 3, Vol. I., pp. 79–85.

BOLD POINT DEPOSITS.

Two or more limestone bodies within granitic rocks occur in a north-easterly-trending belt 1,000 feet long and 200 feet wide in Lot 4, 1 mile north 20 degrees west of the wharf at Bold Point on the east shore of Quadra Island (*see* Fig. 15). The deposits are accessible by a short road and abandoned logging-roads from this wharf. An analysis of a composite sample made up of six chips from various parts of the limestone-belt is as follows:—

Insol.	4.60	CaO	53.35
R_2O_3	0.59	P_2O_5	0.03
Fe_2O_3	0.10	S	0.02
MnO	0.01	Ig. loss	40.23
MgO	0.72	H_2O at 105° C.	0.07

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* Report compiled from published information and from data supplied by J. M. Cummings, B.C. Dept. of Mines. Samples obtained by J. M. Cummings.

A few tons of limestone are reported to have been shipped from this area prior to 1925 but no development has taken place since that time. The limited area of the deposits does not favour large-scale quarrying and no local market exists for a small operation.

Reference.

Bancroft, J. A. (1913): Geology of the coast and islands between the Strait of Georgia and Queen Charlotte Sound, B.C.—*Geol. Surv., Canada,* Mem. 23, p. 79.

THEODOSIA ARM DEPOSIT.*

"In Theodosia Arm . . . between Martin and Ellen Points on the north side (just west of the entrance to Theodosia Arm), a small mass of stratified rocks appears, surrounded on all sides by those of granitoid character. These consist of a grey and white spotted marble, in which kernels and veinlets of pale green serpentine have been developed, with some blackish, hard argillites with rusty joints. The dip and strike are very irregular, but the former appeared to average (strike south 82 degrees east, dip 70 degrees north). These rocks occupy the shore for about 200 feet only." (Dawson, 1887, p. 27B.)

DINNER ROCK DEPOSITS.

Location and Accessibility.—The Dinner Rock limestone-deposits occur on and near the shore of the mainland 8 miles north-west of Powell River and a few hundred feet south-east of a reef known as Dinner Rock. One of the bodies of limestone crops out on the shore cliffs a few feet west of the north-west corner of Lot 5347. Two others lie within a few hundred feet north and north-west of this body in Lot 2362. The property can be reached from Powell River by about 10 miles of road, now completely overgrown, and about ½ mile of trail. A low rocky reef extending out from the shore 100 yards south of the limestone might provide a measure of protection for tug and barge from south-easterly winds, but no shelter exists from westerly winds. The nearest harbour is at Lund, 3 miles to the north.

Geology.—The deposits consist of inclusions or roof pendants, made up entirely of structureless limestone, within granitic and dioritic rocks which are in places distinctly epidotized. The body exposed on the shore cliffs is only 150 feet long and a maximum of 50 feet wide. A second body 300 feet to the north-east is about 300 feet long and 200 feet wide, and a third, ¼ mile to the north-west, is at least 300 feet long in a north-westerly direction and of undetermined width.

No argillite such as has been reported by Bancroft was found in this vicinity.

Analyses.—Samples, each composed of chips, taken at 5-foot intervals across a stated distance, were taken from the limestone body exposed at the shore, and samples, each composed of chips, taken at 10-foot intervals across 100 feet from the second body lying to the north-east of the first. No sample was obtained from the third mass, farther north-west. The analyses of the samples are as follows:—

	Insol.	R_2O_3.	Fe_2O_3.	MnO.	MgO.	CaO.	P_2O_5.	S.	Ig. Loss.	H_2O at 105° C.
Shore exposure—										
North-west end, 68 feet	2.22	0.22	0.25	0.040	2.38	51.64	0.028	0.03	43.08	0.03
South-east end, 80 feet	4.84	0.44	0.67	0.041	2.82	49.23	0.051	0.17	41.66	0.08
North-eastern body—										
North-west 100 feet	0.40	0.82	0.25	0.036	3.70	50.87	0.030	0.05	43.96	0.14
Middle 100 feet	1.20	0.15	0.14	0.048	3.32	51.69	0.025	0.03	43.26	0.16
South-east 100 feet	0.10	0.22	0.21	0.021	6.18	48.62	0.035	0.02	44.54	0.10

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* Dawson, G. M. (1887): Report on a geological examination of the northern part of Vancouver Island and adjacent coasts—*Geol. Surv., Canada,* Ann. Rept., New Ser., Vol. 2, p. 27B.

Development and Operation.—No development has been carried on by the present owner of Lot 2362, B. Whalen, of Westview, or by his predecessors. The grade and size of the known deposits, moreover, do not justify development unless other adjacent limestone bodies are found. Though no readily available harbour exists to facilitate transportation of limestone from this locality by water, its accessibility by road to one possible market, Powell River, justifies further search for limestone-deposits in this vicinity.

Reference.

Bancroft, J. A. (1913): Geology of the coast and islands between the Strait of Georgia and Queen Charlotte Sound, B.C.—*Geol. Surv., Canada,* Mem. 23, p. 66.

HARDY ISLAND DEPOSIT.*

"On Hardy island, Jervis inlet, the limestone occurs as a narrow band with a visible width of a little over fifty feet. This band strikes across the island and runs inland on Nelson Island for a short distance [*see* page 103 of this report—*Ed.*]. In part the rock is flat lying and in part highly contorted. It is a fine-grained, impure crystalline limestone, with a pitted or fluted weathered surface. It holds long areas of siliceous material filled with pyrite, which coincide with the bedding planes and represent subsequent mineralization."

". . . the limestone is closely associated with finely banded siliceous schists." (LeRoy, 1908, pp. 14, 15.)

NELSON ISLAND DEPOSIT.

Location and Accessibility.—Limestone occurs in the north-western part of Nelson Island near the head of Blind Bay. It outcrops on the shore in Lot 5377 and is reported to extend inland up the steep slopes of Nelson Island for at least ½ mile across Lots 5377 and 5570. The property can be reached from Pender Harbour, between 13 and 14 miles by boat to the south. Blind Bay is large and provides excellent shelter for shipping. Rock from a quarry on the property has been dumped at the shore to form a jetty extending to low-tide mark, hence adequate facilities for loading ships could readily be constructed.

Geology.—The limestone outcrops in a belt at least 200 and possibly as much as 400 feet wide, striking south 30 degrees east. At the shore the limestone is bounded on the north by a slightly gneissic grey porphyry, possibly an altered lava. About 400 feet farther north this porphyry is intruded by a grey granitic rock. On the south the limestone is bounded by a series of green distinctly banded tuffs which outcrop southerly along the shore for about 1,400 feet as far as a second granitic body. The tuffs strike from south 10 degrees to south 30 degrees east and dip from 60 to 90 degrees westward. Similar attitudes exist in the limestone where, however, some isoclinal folding is evident.

A few discontinuous dykes cut the limestone.

Overburden is relatively light.

The rock is white to cream in colour and relatively fine-grained. It is distinctly and finely bedded.

Analyses.—Four samples, each made up of chips, taken at 4-foot intervals measured at right angles to the strike of the limestone-belt, and representing widths of from 16 to 40 feet, were taken in the quarry in the central part of the belt about 300 feet from the shore. Dyke-rock was excluded in sampling. The analyses of these samples are as follows:—

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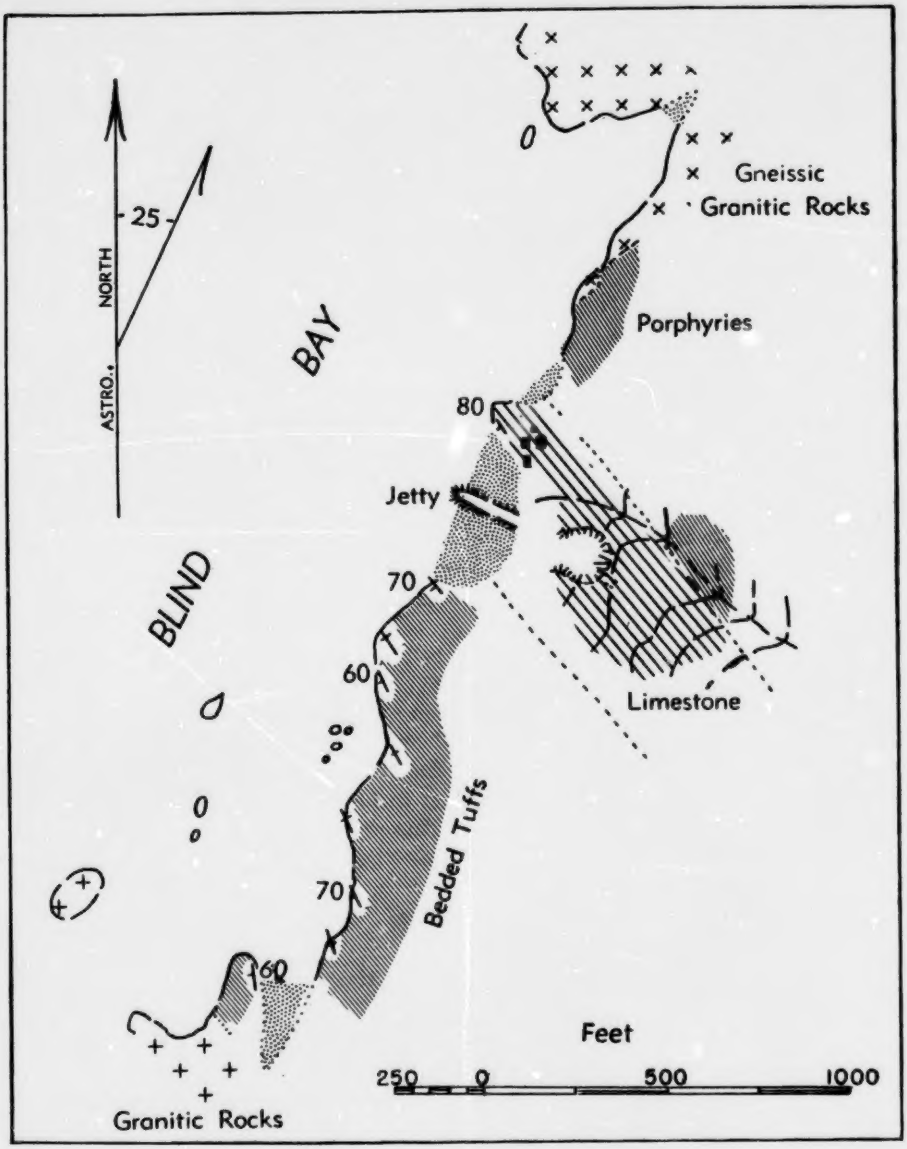
* LeRoy, O. E. (1908): Preliminary report on a portion of the main coast of British Columbia and adjacent islands included in the New Westminster and Nanaimo districts—*Geol. Surv., Canada,* Rept. No. 996.

Distance from North End.	Insol.	R_2O_3.	Fe_2O_3.	MnO.	MgO.	CaO.	P_2O_5.	S.	Ig. Loss.	H_2O at 105° C.
0– 16 feet	1.82	0.24	0.21	0.081	0.76	53.94	0.012	0.02	42.94	0.04
16– 44 feet	1.58	0.32	0.43	0.157	1.56	52.87	0.012	0.06	43.18	0.18
44– 84 feet	1.64	0.26	0.12	0.054	0.38	54.15	0.016	0.01	43.33	0.12
84–108 feet	4.16	0.26	0.31	0.111	0.42	52.61	0.012	0.01	42.12	0.21



25
NORTH
ASTRO.
BAY
BLIND
Gneissic Granitic Rocks
Porphyries
80
Jetty
70
60
70
60
Limestone
Bedded Tuffs
Granitic Rocks
Feet
250
0
500
1000

Fig. 18. Sketch-map of west side of Nelson Island.

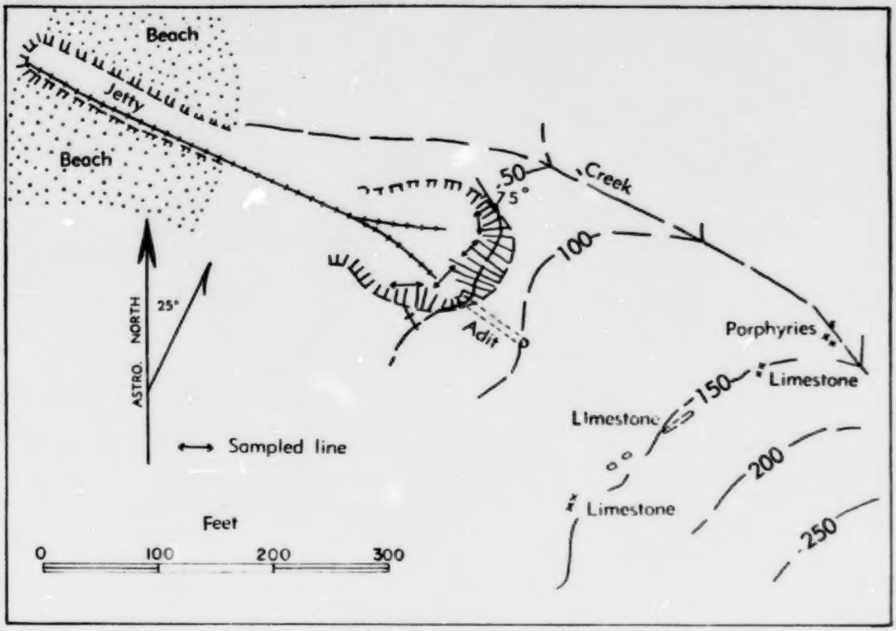


Fig. 19. Nelson Island quarry. Contour interval, 50 feet.

Development and Operation.—The property was developed by the International Lime Corporation, Limited; it was idle in 1945 and had not been worked since about 1937. The registered owner of the property is Andrew J. Jorgenson, of Tacoma, Wash.

A quarry about 100 feet in diameter and with a face up to 60 feet high has been opened in the central part of the limestone-belt on a knoll near the base of the steep mountainside of Nelson Island. An adit has been driven for 75 feet into the face of the quarry and several trenches dug to expose the limestone at the surface 200 feet beyond the face. The jetty mentioned above was constructed from rock obtained from the quarry. A kiln is reported to exist on the property. Quarry and jetty were overgrown with young alder in 1945.

The quarry could be advanced as far as the trenches, 200 feet from the present face and 150 feet above the present floor, without encountering any major physical problems, but beyond this point the steep slope of the land surface would require quarrying in benches at successively higher levels.

Reference.

LeRoy, O. E. (1908): Preliminary report on a portion of the main coast of British Columbia and adjacent islands included in the New Westminster and Nanaimo districts—*Geol. Surv., Canada,* Rept. No. 996.

MIDDLE POINT DEPOSIT.*

" Crystalline limestones occur at Middle Point (5 miles south-east of Pender Harbour), on the main coast, in a few small contorted and faulted beds, which are lenticular and pinch out along strike.

". . . the limestone is closely associated with finely banded siliceous schists." (LeRoy, 1908, p. 15.)

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* LeRoy, O. E. (1908): Preliminary report on a portion of the main coast of British Columbia and adjacent islands included in the New Westminster and Nanaimo districts—*Geol. Surv., Canada,* Rept. No. 996.

Salmon Arm Deposit.[*]

"A large body of white crystalline limestone is reported to occur a short distance from tide-water on Salmon Arm (Jervis Inlet)."

Lynn Creek Deposit.[†][‡]

Burwash[†] reports the presence of limestone with associated zinc mineralization near the head of Lynn Creek, north of Vancouver.

CALCAREOUS DEPOSITS IN THE MIDDLE JURASSIC TO RECENT SUCCESSION.

GENERAL.

Upper Jurassic to Recent sediments and volcanics in the Georgia Strait area, as indicated above, generally do not contain valuable calcareous deposits. However, an occurrence of limestone in Upper Jurassic rocks near Harrison Lake, B.C., is reported (page 37, foot-note), and impure limestone occurs in the Middle Eocene Metchosin series of the Olympic Peninsula, Wash. Calcareous sandstones are known from a few localities at the base of the Upper Cretaceous succession on the shores of the Georgia Strait, from the marine Oligocene or Miocene sediments on Southern Vancouver Island, and in the Recent delta of the Fraser River. Marls are reported from the Eocene or Oligocene sediments near Bellingham, Wash., from the Oligocene or Miocene sediments on Southern Vancouver Island, and are now accumulating in Cheam Lake at the eastern end of the Fraser Valley. One deposit of travertine, large enough to have been worked, occurs in interglacial sediments at McMillin, near Tacoma, Wash. Shell-mounds accumulated in recent times on the sites of Indian villages are common, and at least one has proved sufficiently large and high grade to justify mining. Shell-sands of very limited extent are produced by wave and current action during storms and have been worked by individuals during periods of unemployment.

DESCRIPTION OF OCCURRENCES.

Calcareous Deposits at Departure Bay.

Location and Accessibility.—A calcareous deposit, referred to by Clapp (1913, pp. 55, 56, 123, 124) as an impure calcarenite, occurs at two places on the north shore of Departure Bay, at and ½ mile east of the Dominion Biological Station respectively. Similar rocks are mapped in three small areas about 2½ miles north-west of the Biological Station. The deposits are accessible by road from Nanaimo, 4 miles south of Departure Bay.

Geology.—The deposits consist of a green sandstone in which occurs a greater or less amount of calcium carbonate, generally as equidimensional spherical to angular grains 1 to 2 mm. in diameter, and in the finer-grained cementing material. Some of the calcium carbonate grains are composed of shell fragments, and some may be oolites of chemical origin. All the deposits lie at the base of the Upper Cretaceous succession and rest with or without basal conglomerate unconformably on the Vancouver series, here composed of greenstone, which clearly provided most of the detrital material in the sandstone. In the section exposed on the shore near the Biological Station a total thickness of only about 50 feet of sandstone and basal conglomerate, all dipping about

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[*] Cummings, J. M. (1937): Possibilities for the manufacture of mineral wool in British Columbia—*B.C. Dept. of Mines.*

[†] Burwash, E. M. J. (1918): The geology of Vancouver and vicinity—*Univ. of Chicago Press.*

[‡] Phemister, T. C. (1945): The Coast Range batholith near Vancouver, B.C.—*Geol. Soc., London,* Quarterly Journal, Vol. 51, pp. 61–64.

20 degrees southward into Departure Bay, is present. A few layers are relatively rich in calcium carbonate, and one such layer, about 2 inches in thickness, has the following analysis:—

Insol.	20.40	CaO	39.5
$R_2O_3 + Fe_2O_3$	5.96	Ig. loss	32.2
MgO	1.88		

An analysis given by Clapp (1914, p. 124) of a similar calcareous sandstone is as follows:—

Insol. mineral matter	15.42
Ferric oxide and alumina	5.40
Lime*	42.41
Magnesia*	0.94

A succession similar in character and comparable in thickness to that at the Biological Station is exposed on the shore ½ mile east of the station where, however, the beds dip steeply eastward and south-eastward. The deposits 2½ miles north-west of the station have not been examined by the writer.

Development and Operation.—Clapp in 1914 reported that a test quarry had been opened on the deposit at Departure Bay, but no subsequent development has evidently taken place. The extremely limited quantity of sandstone rich in calcareous matter, and unsatisfactory grades even of this material, eliminates possibilities of commercial operation of the deposit.

MIDDLE EOCENE LIMESTONES OF THE OLYMPIC PENINSULA.

Limestone occurs in close association with basaltic volcanic rocks of the Middle Eocene Metchosin series of the Olympic Peninsula. This series, which outcrops along the northern, eastern, and southern borders of the Olympic Mountains, consists of "at least 30,000 feet of alternating argillites, graywackes, volcanic rocks, red limestones, . . ." (Park, 1941, pp. 439, 440.)

Park adds: "The lavas, particularly the pillow basalts and agglomerates, are associated with intergrading reddish and chocolate-colored and light-greenish limestones, argillites, and tuffs. The beds of red siliceous limestones, although they are thin and lenticular and make up a very small percentage of the whole section, have particular interest because they contain most of the manganese deposits. These red limestones are widely distributed, but they are highly lenticular. The beds range in thickness from a knife edge to 300 feet, but most are less than 25 feet thick. The red sediments for the most part rest upon the tops of flows, but some red beds lie within or below flows, or lap around their ends. Locally they are found between pillows in the pillow lavas or in the cores of the pillows. Fragments of red rocks occur in the agglomerates, and blocks as much as 30 feet or more in diameter are engulfed in the lavas.

"The red color of these rocks is due to finely divided hematite. Most of the impure limestone contains from 1 to 5 per cent. of manganese oxide (MnO), which probably is combined in the main with silica but possibly in part with carbonic oxide."

S. H. Green (1945, p. 31) notes in addition that "the known (limestone) beds are non-fossiliferous, markedly siliceous, and commonly argillaceous. The iron content may be high. In texture, the limestone is particuiarly fine grained—porcelaneous in general; it is hard, very brittle, and breaks with a conchoidal fracture. Most exposures are maroon-colored, apparently owing to an original content of ferric iron; but in some places brown tones are a result of weathering and the unaltered rock is a distinct bluish or greenish gray in color."

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* Equivalent to calcium carbonate 75.73 and magnesium carbonate 1.96.

Occurrences of limestone noted in the reports on the manganese deposits of the Olympic Peninsula are indicated on the accompanying map. So far as is known, none of these limestones have been quarried or mined except for the production of manganese. Glover (1936A), however, adds that "the beds warrant some investigation with, for example, natural cement rock and lithographic stone in mind."

Analyses of some of the red limestones from various parts of the Olympic Peninsula are quoted by Park (1946).

References.

Glover, S. H. (1936A): Nonmetallic mineral sources of Washington with statistics for 1933—*Wash. Div. Geol.*, Bull. 33.

Green, S. H. (1945): Manganese resources of the Olympic Peninsula, Washington—*Wash. Div. Mines and Mining*, Rept. of Investig. No. 7.

Park (*Jr.*), C. F. (1941): Manganese resources of the Olympic Peninsula, Washington—*U.S. Geol. Surv.*, Bull. 931B.

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McMILLIN TRAVERTINE DEPOSIT.

Location and Accessibility.—The McMillin deposit is situated ½ mile east of McMillin Station on the Northern Pacific Railway, about 10 miles south-east of Tacoma. It lies in the North-west Quarter of Section 18, Township 19 north, Range 5 east.

Geology.—The deposit consists of fluvioglacial sands and gravels, mapped by Willis and Smith (1899)[*] as of interglacial age, saturated and overlain by earthy or pulverulent calcareous material. Harder nodules of nearly pure calcium carbonate occur within the deposit. The reason for the local concentration of this spring-deposited material is not known. No similar deposits are reported from this vicinity, and no limestones occur in bed-rock within many miles of this locality.

Development and Operation.—At one time the deposit was worked for agricultural limestone, fluxing stone, and even burned for lime. A pit, estimated to average 15 to 20 feet in depth 100 feet in width and 200 feet in length, has been opened on the deposit. A plant, equipped with a miniature oil-fired rotary kiln 2½ feet in diameter and 30 feet long, is situated adjacent to this pit. The operation is abandoned and the plant no longer in operating condition.

CHEAM LAKE MARL.

Location and Accessibility.—Cheam Lake is situated in the eastern part of the Fraser Valley, 9 miles east of Chilliwack, in the North-west Quarter of Section 5, the North-east Quarter of Section 6, the South-west Quarter of Section 8 in Township 3, Range 28, west of the 6th meridian, and on the Cheam No. 1 Indian Reserve. It is less than ½ mile from the Cariboo Highway, and about 1 mile by road from Popkum Station on the Canadian National Railway.

Geology.—The deposit consists of a layer of brownish to white jelly-like marl containing scattered snail and pelecypod shells, accumulated on the floor of the shallow lake in post-Glacial time. The marl is reported to be from 4 to 12 feet thick and to lie on 2 feet of blue clay and this, in turn, to rest on sand. The chief impurities consist of mud, brought in by a stream from the south and concentrated near its mouth, and wind-blown dust. Organic matter, nitrogen, and sulphur are present in greater amounts than in most of the older limestone-deposits of the Georgia Strait area, but magnesia content is very low (*see* analyses).

In addition to the marl within the lake, a second deposit is reported to underlie to a depth of as much as 18 feet an area of low land, about 4 acres in extent, apparently a former arm of Cheam Lake, in the South-west Quarter of Section 8.

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[*] Willis, B., and Smith, G. O. (1899): Description of the Tacoma quadrangle—*U.S. Geol. Surv.*, Geol. Atlas, Tacoma Folio, No. 54.

Development and Operation.—The marl is being recovered from Cheam Lake by the Fraser Valley Chemicals under royalty from Messrs. Munroe and Elgy, owners of the North-west Quarter of Section 5 and the South-west Quarter of Section 8 respectively.

The marl is pumped from the lake-bottom through a 3¾-inch pipe by a 2½-inch centrifugal pump driven by a 6-cylinder Chevrolet motor housed on a raft fixed near shore. The mouth of the pipe is fitted with fixed cutting-blades and is moved back and forth over a nearly vertical working-face of the marl. The slurry is pumped from the raft to a settling tank, 12 feet by 14 feet by 12 feet deep, where it is left for several days, then transferred to bins, with total floor area of about 1,500 feet, which are filled to a depth of several feet. After a period of from one to several months, depending on the amount of dry, warm weather, the marl from these bins is spread on a platform of about 2,300 square feet in area to a depth of about 3 inches and periodically raked. After several days of this final drying the moisture content of the marl is reduced to about 40 per cent. The marl is then passed through a hammer-mill, of about 1½-tons-per-hour capacity, to break up any lumps, and the resulting product sacked ready for distribution. The capacity of the plant, which is definitely limited by the bin capacity, is about 50 to 100 tons per season of air-dried marl.

The amount of marl available in Cheam Lake is very difficult to estimate in view of the indefinite moisture content of the jelly-like material. The following analyses have been made of three samples of material pumped from the lake after it had been partly dried in bins and are quoted both on a moisture-free basis and as received. The calcium carbonate content of the three samples "as received"—that is, of partly dried marl—ranged from 35.4 to 37.9 per cent.

	Insol.	R_2O_3.	Fe_2O_3.	MnO.	MgO.	CaO.	P_2O_5.	S.*	Ig. Loss.	N.*	Organic.*†	H_2O at 105° C.
No. 1—												
Moisture-free	13.10	0.81	1.06	0.046	0.08	40.26	0.049	0.67	44.43	0.51	5.10	0.0
As received	......	......	......	......	......	*19.9*‡	......	......	......	......	......	50.6
No. 2—												
Moisture-free	8.70	0.67	0.77	0.032	0.10	44.00	0.040	0.55	45.07	0.43	3.90	0.0
As received	......	......	......	......	......	*21.3*‡	......	......	......	......	......	51.7
No. 3—												
Moisture-free	5.45	0.25	0.72	0.029	0.20	46.40	0.031	0.59	45.97	0.51	3.00	0.0
As received	......	......	......	......	......	*20.1*‡	......	......	......	......	......	55.0

* Included in ignition loss.
† Includes carbon.
‡ Calculated from CaO content of moisture-free sample.

SHELL-MOUNDS.

*Kuper Island.**

Location and Accessibility.—The Kuper Island shell-deposit is situated on Clam Bay at the north end of Kuper Island, 20 miles south-east of Nanaimo, B.C. This island can be reached from Vancouver Island or from the Mainland by launch or by tug and barge.

Geology.—The shell-mound consists of an old Indian midden, accumulated probably over a period of centuries. Most of the deposit is made up of clam-shells, bones, ashes, assorted debris, and rare human artifacts. Mounds composed largely of mussel-shells are found in a few places at the base of the deposit. The relative freedom from sand is considered to be evidence of the absence of wave and current action during the formation of the mound. The deposit is reported to have covered an area of about 12 acres to a depth of as much as 15 feet.

---

* From information provided by A. E. Pickford, of the Provincial Museum, Victoria, and J. A. Robinson, of the West Coast Shell Company, New Westminster.

Development and Operation.—The deposit has been worked in recent years by West Coast Shell Company, of New Westminster, B.C., and has now been almost exhausted. During the period of operation the shell was hauled by drag-line to a central bunker, washed and jigged to remove most of the impurities, flumed to a dock, drained, then loaded by drag-line onto a scow to be hauled to the New Westminster plant. At New Westminster the shell was unloaded by a clam-shell bucket, bulldozed to a bunker, passed through a 6- by 60-foot rotary dryer, thence to a Dillon screen. Two screen products, minus 5/16 inch plus 5½ mesh, and minus 5½ mesh plus 12 mesh, used for hen and chick grit, respectively, were recovered. Oversize was passed through a hammer-mill and returned to the circuit and undersize pulverized. The latter product is mixed with feed for poultry and stock. The New Westminster plant is being supplied with shell from clam and oyster factories and the operators are planning to work another deposit outside the Georgia Strait area.

Other Shell-deposits.

Another shell-deposit exists at the northern end of Denman Island, 5 miles east of Courtenay. This deposit, like the one at Kuper Island, is made up of the shells of clams and mussels together with broken utensils, bones, ashes, etc. Over a considerable area near the shore the shells are reported to be cupped, one inside the other, as if rolled into a common orientation by wave-action. The deposit is about 10 acres in extent and up to about 9 feet deep. Much of the shell has, however, been rendered friable, perhaps by age or fire, and it has not proved possible to recover a sufficient quantity of poultry grit to make the deposit commercial.*

Many other similar shell-mounds† are known in the Georgia Strait area, but because of the small size, or deficiencies in grade and character of the shell, have not proved commercial.

SHELL-SANDS.

In localities, such as at False Creek in Vancouver, shell-sands may accumulate entirely as a result of wave and current action along the shore. These deposits, a fraction of an inch in depth, form after violent storms as a result of transportation of clam-shells to the shore and washing by the waves. Such layers of shell and shell fragments can be collected by means of a basket-like scoop, screened, and sold as poultry grit. The recovery of shell-sand by individuals was carried on during times of unemployment close to such populated centres as Vancouver, but the extremely limited and ephemeral character of the deposits discourages their operation by large-scale high-capitalized organizations and by individuals during periods of high wages. As far as is known, no recovery of these shell-sands was carried on during 1946.

---

* From information by A. E. Pickford and J. A. Robinson.

† Smith, Harlan I. (1903): Shell heaps of the Lower Fraser River—*Am. Mus. Nat. Hist.*, Jesup North Pacific Expedition.

† *Idem* (1907): Archæology of the Gulf of Georgia and Puget Sound—*Am. Mus. Nat. Hist.*, Jesup North Pacific Expedition.

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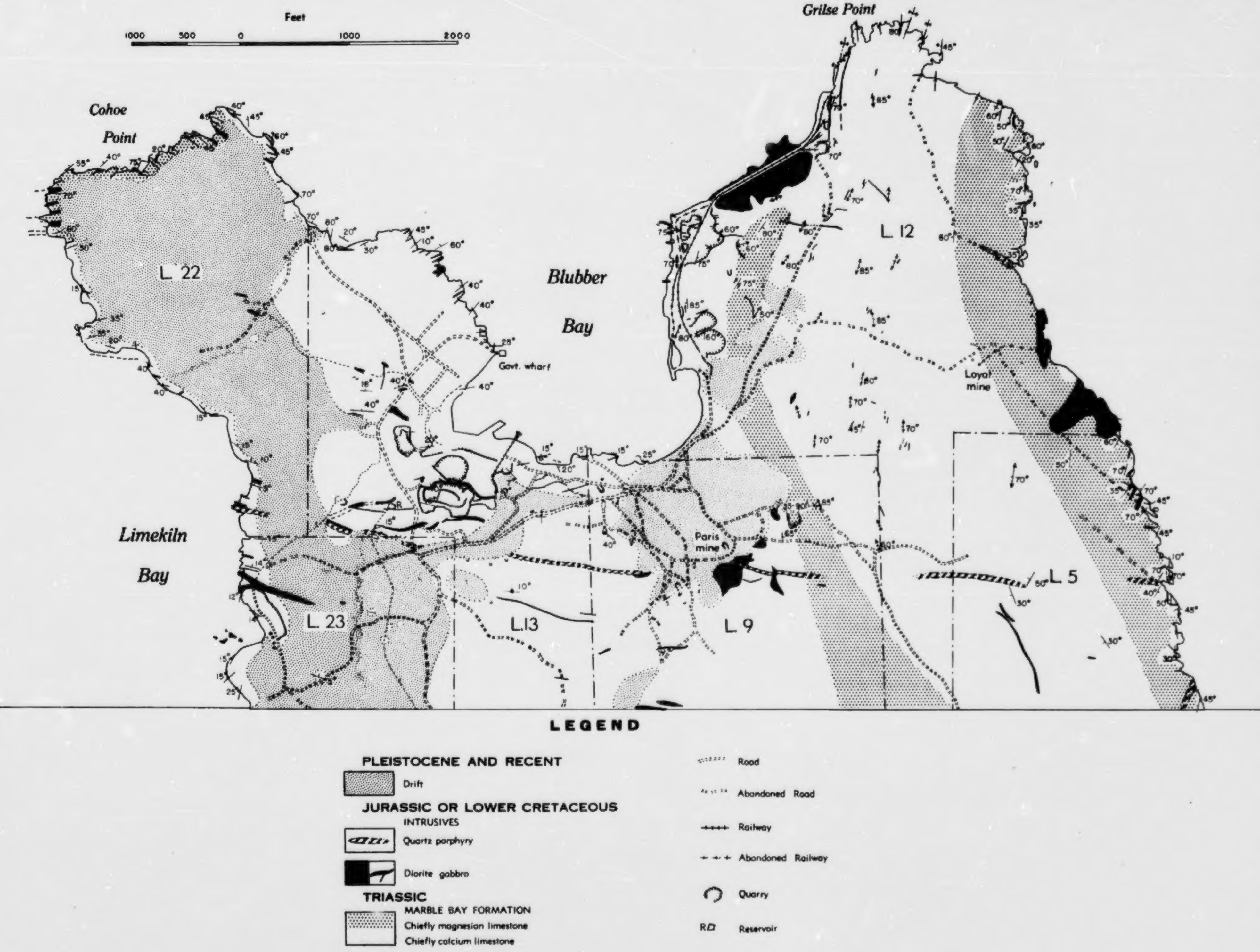
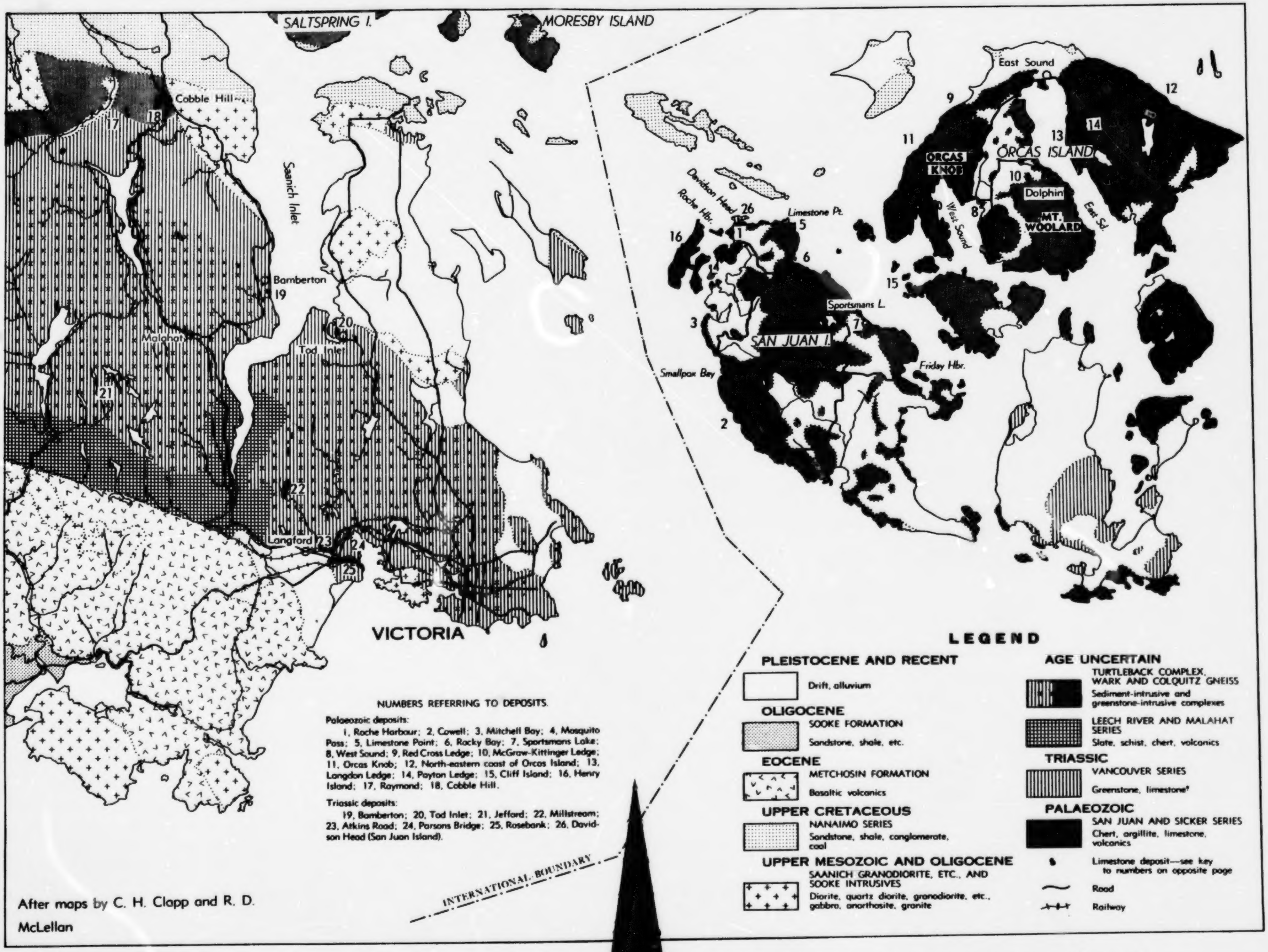

Feet
1000 500 0 1000 2000
Grilse Point
Cohoe Point
Blubber Bay
Limekiln Bay
L. 22
L. 12
L. 23
L.13
L. 9
L. 5
Govt. wharf
Loyal mine
Paris mine
R
LEGEND
PLEISTOCENE AND RECENT
Drift
JURASSIC OR LOWER CRETACEOUS
INTRUSIVES
Quartz porphyry
Diorite gabbro
TRIASSIC
MARBLE BAY FORMATION
Chiefly magnesian limestone
Chiefly calcium limestone
Road
Abandoned Road
Railway
Abandoned Railway
Quarry
R Reservoir

Figure 10.– Blubber Bay Area


SALTSPRING I.
MORESBY ISLAND
Cobble Hill
17
18
Saanich Inlet
Bamberton
19
Malahat
21
20
Tod Inlet
22
Langford
23
24
25
VICTORIA
East Sound
9
12
11
14
13
ORCAS KNOB
ORCAS ISLAND
10
Dolphin
Davidson Head
Roche Hbr.
26
Limestone Pt.
5
1
16
West Sound
8
MT. WOOLARD
East Sd.
6
15
Sportsmans L.
3
7
SAN JUAN I.
Smallpox Bay
Friday Hbr.
2
INTERNATIONAL BOUNDARY
NUMBERS REFERRING TO DEPOSITS.
Palaeozoic deposits:
1, Roche Harbour; 2, Cowell; 3, Mitchell Bay; 4, Mosquito Pass; 5, Limestone Point; 6, Rocky Bay; 7, Sportsmans Lake; 8, West Sound; 9, Red Cross Ledge; 10, McGraw-Kittinger Ledge; 11, Orcas Knob; 12, North-eastern coast of Orcas Island; 13, Langdon Ledge; 14, Payton Ledge; 15, Cliff Island; 16, Henry Island; 17, Raymond; 18, Cobble Hill.
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After maps by C. H. Clapp and R. D. McLellan
LEGEND
PLEISTOCENE AND RECENT
Drift, alluvium
OLIGOCENE
SOOKE FORMATION
Sandstone, shale, etc.
EOCENE
METCHOSIN FORMATION
Basaltic volcanics
UPPER CRETACEOUS
NANAIMO SERIES
Sandstone, shale, conglomerate, coal
UPPER MESOZOIC AND OLIGOCENE
SAANICH GRANODIORITE, ETC., AND SOOKE INTRUSIVES
Diorite, quartz diorite, granodiorite, etc., gabbro, anorthosite, granite
AGE UNCERTAIN
TURTLEBACK COMPLEX, WARK AND COLQUITZ GNEISS
Sediment-intrusive and greenstone-intrusive complexes
LEECH RIVER AND MALAHAT SERIES
Slate, schist, chert, volcanics
TRIASSIC
VANCOUVER SERIES
Greenstone, limestone'
PALAEOZOIC
SAN JUAN AND SICKER SERIES
Chert, argillite, limestone, volcanics
Limestone deposit—see key to numbers on opposite page
Road
Railway

Figure 4. – San Juan Islands:— Southeastern [illegible]ouver Island, geology and limestone deposits.